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Infrastructure investments and public transport use: Evidence from Lahore, Pakistan

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Abstract

In many cities in the developing world, public transport infrastructure has not kept up with dramatic urban growth. Car ownership is growing rapidly among wealthier households, increasing congestion and emissions, and potentially leading to patterns of land use that make access difficult for the poor. To address these challenges, more than a hundred cities in the developing world have recently built mass transit systems and many more are considering doing so. However, there has been limited rigorous analysis of the impacts of these investments. In this paper, we provide a credible causal estimate of the effect of mass transit on commuting. We use areas which were slated for transit routes that have not yet been built as a comparison group for areas connected by the new Bus Rapid Transit line. Within these comparison areas, we select areas that were similar on observables before the transit was built, and collect data in these areas. We find that access to the new transit line reduced both the time and cost of commuting. We find robust evidence that the line has caused workers to switch from private to public modes of transport. We estimate that the introduction of this transit line led to a 24% increase in public transport use among commuters in nearby areas, with approximately 35,000 commuters switching to public transit citywide. We also document that the mass transit line attracts a significantly larger proportion of highly educated riders than those who rode public transport before its introduction, suggesting that its high quality and reliability make public transport options acceptable to a broader part of the population. The capital cost of the transit line was substantial, and its fare is subsidized. However, the majority of riders are willing to pay a substantially higher fare, suggesting it could be made more financially sustainable with better targeting of the subsidy. The results suggest the potential of mass transit investments to make urbanization in the developing world more sustainable.

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1 Introduction

In many cities in the developing world, public transport infrastructure has not kept up with dramatic urban growth. The World Bank (2013) predicts that 96% of population growth in developing countries in the next two decades will be urban. Many people in these urban areas have limited access to public transport; for example in Sub-Saharan Africa, only 5% of urban trips are on public transport (Pojani and Stead, 2015). Car ownership has increased by an order of magnitude in countries such as India and China in the past two decades. But private vehicle ownership also creates substantial externalities of congestion and pollution (Timilsina and Dulal, 2010). In addition, in these cities many households will not be able to afford private vehicles; public investments that serve private vehicle users and resulting patterns of land use may reinforce inequitable access to urban economic opportunities.

As a result, there has been a major push from governments and aid agencies to build urban mass transit infrastructure in the developing world. Several hundred cities worldwide have built mass transit systems either by rail or dedicated busway (Bus Rapid Transit), with well over a hundred built since 2000 (Gonzalez-navarro and Turner, 2016; EMBARQ, 2017). The high-speed, reliable transport on these services can reduce duration and variability of commute time for those who use public transport. However, economic estimates from developed countries have suggested that the costs of mass transit may exceed the benefits, with limited positive externalities on congestion and pollution. This is because they are used below full ridership capacity and primarily attract users who otherwise would have traveled by bus, not private vehicle (Winston and Maheshri, 2007; Baum-Snow and Kahn, 2005).[1]

This literature focuses almost exclusively on industrialized countries, part of a more general under-representation of the developing world in studies of urban economics (Glaeser and Henderson, 2017). Yet there are many reasons to expect public transit to have different impacts in a city like Lahore or Bangkok than in Charlotte, NC or Buffalo, NY. For example, developing country cities typically have higher levels of traffic congestion (Cookson and Pishue, 2017), implying that mass transit creates greater time savings relative to driving and buses. Higher congestion may also lead to a larger number of people who find it optimal to take another mode to get to the mass transit line instead of taking a private vehicle or taking a bus all the way to their destination (consistent with the theoretical model of

[1]This literature has primarily considered rail systems. However, in recent years, more cities have built Bus Rapid Transit systems, in which buses are given dedicated right-of-way so they can move at higher speeds. These systems have substantially lower capital costs than rail. Wright and Hook (2007) estimate that on average BRT systems cost 4 to 10 times less than a LRT system and 10 to 100 times less than an underground or elevated rail system. The first line built in Lahore is a Bus Rapid Transit system.

Baum-Snow and Kahn (2005)).[2] On the other hand, the opportunity cost of time is lower in developing country cities due to lower wages, suggesting the impact of these time savings may be lower. All this has implications for both the cost effectiveness of transit (through increasing the number of riders per vehicle) as well as through positive externalities on congestion and the environment (through switching from private to public transport commuting).

In this paper, we quantify the impact of a new urban mass transit line in Lahore, Pakistan on commuting and the use of public transport. We identify areas slated for potential routes that have not yet been built as a comparison group for areas with new access to a transit line. Of seven lines included in an original transit plan, one was built first (as a BRT) in order to improve traffic flow on a major artery road, a second is under construction (as a light rail), while the others are still in the original plan but do not currently have a date planned for implementation. We use areas close to stops on the new line as "treatment" areas, and close to stops on the other lines in the original plan as "control" areas. The route and order of routes built were maintained unchanged from a technical plan developed by a previous government, reducing the likelihood of selection of areas for new transit access on unobservables such as political importance.

This approach is arguably the most plausible identification strategy used in the literature from developed countries (Redding and Turner, 2015). However, it requires the assumption that the order of lines to be built is uncorrelated with unobservables that affect the outcome variable. We improve on this strategy to relax this assumption in two ways. First, we use matching methods to select and sample data from areas which are similar on observables before the first transit line was built. To address the possibility of pre-trends, we match on data from two points in time before transit was built.

Second, we incorporate fixed effects for bands of distance from the planned stop. This effectively compares areas less than 1 km from a built stop with those less than 1 km from a planned stop. Similarly, it compares areas 1-2 km from a built stop with those 1-2 km from a planned stop, and so on.

Thus we require a much weaker assumption for identification of the causal effect of access to transit: areas that were both slated for a transit stop, both the same distance from the planned stop, and were similar on observables both twelve and three years before transit was built, should not differ on unobservables that affect our outcomes of interest. We also use recall data to construct a quasi-panel

[2]Consistent with this, in our setting, we observe commuters traveling much further to a transit stop than the typical 3km catchment area assumed in developed countries (Billings, 2011).

dataset, so that the assumption is further weakened to require only that such observably similar areas have parallel trends. This combination strategy ensures that the treatment group is comparable to the comparison group, so we can attribute differential changes to the introduction of the new transit. In this paper, we discuss the impact of this transit investment on commuting and public transport ridership.[3]

We find that access to the new transit line reduced both the time and money cost of commuting. We also find a robust effect of the line on workers switching from private modes to public transport. We estimate that the introduction of this transit line led to a 1.5 percentage point increase in public transport use among commuters in nearby areas, or a 24% increase over the base. We calculate that this corresponds to approximately an 8% increase for the city as a whole. This pattern is consistent with descriptive statistics from a survey of riders we conduct, approximately half of whom report using only private modes such as motorbikes, autorickshaws and cars in the past for the same trip they now make on transit.

Our descriptive analysis suggests that the mass transit line attracts a much larger proportion of highly educated riders than those in the same areas who rode public transport before its introduction. Our causal estimates also that educated commuters are just as likely to switch to public transport in response to the new transit line. This suggests that its high quality and reliability make public transport options acceptable to a broader part of the population.

The capital cost of the transit line was substantial, at about 280 million USD (29 billion PKR), or 18 million USD per mile - on the high end for a Bus Rapid Transit system because elevated lanes were built for a large portion of the route. Its fare is subsidized, with a flat fare of about 20 cents per trip regardless of length. However, three-quarters of riders report they would be willing to pay a 50% higher fare for the same trip, and almost half say they are willing to pay double the fare, suggesting it could be made more financially sustainable with better targeting of the subsidy.

Our paper relates to the literature on the effects of urban transport connections (see Redding and Turner (2015) for a review). Only a few studies in this literature include data from developing country cities (Tsivanidis, 2017; Gonzalez-navarro and Turner, 2014; Baum-Snow *et al.*, 2017)[4].

Some of these papers (Gibbons and Machin, 2005; Glaeser *et al.*, 2008; Billings, 2011) use natural

[3]We pre-registered the evaluation design with the 3IE database (RIDIE) under ID RIDIE-STUDY-ID-570e7e4ce1a59. This paper focuses on the transport related outcomes (area 1 in the database entry), and extends the analysis planned in the registry to explicitly incorporate analysis of use of public transport. A companion paper investigates the impacts on labor markets and the structure of urban economic activity, i.e. area 2 outcomes in the registry entry.

[4](**?**) uses an alternative approach using Indian data to identify the effects of higher commuting costs due to the geographic spread of a city on similar outcomes.

experiments such as the introduction of new lines or comparison lines; in general these still rely on before and after changes to identify the effect of interest, relying on strong assumptions about time trends, or use areas further from stations as a comparison group, which relies on strong assumptions about the comparability of these areas. Some papers (such as (Baum-Snow *et al.*, 2017; Tsivanidis, 2017)) also incorporate instruments based on historical or geographic factors that made some areas more likely to receive new transport connections. Because we have an original plan with a number of routes for comparison, in addition to rich baseline data to allow for matching on baseline observables that determined line sequencing, we are able to improve on the identification strategies used in most of this literature.

In addition, most work on this topic uses aggregate sources of data such as real estate prices, night lights or repeat cross section census data (Baum-Snow and Kahn, 2000, 2005; Gonzalez-navarro and Turner, 2014)). Such data cannot be used to distinguish between changes for an existing population and sorting mechanisms, in which one group of households moves in and perhaps displaces existing residents in an area with new access to transit. Thus a net increase in transit use in an area could simply represent more transit users moving in after a station opens. A few studies (Glaeser *et al.*, 2008; Tsivanidis, 2017) test this directly, and have found substantial evidence of residential sorting. Because we collect household residential histories, we are able to rule out sorting for our estimates of interest.

Finally, these papers focus on changes in population, labor and housing markets; in many cases they do not observe commuting behavior directly. While our broader project investigates effects of Lahore's mass transit system on these markets, in this paper we focus specifically on commuting patterns, and in particular sustainable commuting on public transport. Thus this paper relates most closely to Baum-Snow and Kahn (2000) and Baum-Snow and Kahn (2005), who study the impact of US urban rail transit expansions on public transport ridership. Baum-Snow and Kahn (2005) find that these effects vary dramatically from negative to positive depending on the city and the distance from the central business district, but the modal estimate is insignificantly different from zero. In particular, their results for many cities indicate a *negative* impact on areas close to the central business district. This may be suggestive of sorting, which they are not able to address with the repeat cross section census data used. In contrast, we find a robust positive impact, which we can attribute to changes in behavior of existing residents, not sorting.

The remainder of the paper proceeds as follows. Section 2 describes the setting and the new transit infrastructure we study. Section 3 details our empirical strategy. Section 4 describes the data. Section 5 presents results, and Section 6 concludes.

2 Setting and new transit infrastructure

Lahore, Pakistan is the country's second largest city and the capital of its most populous province, Punjab. It is a metropolitan area with a population of 10 million, covering an area of about 2,000 square kilometers.

Before the mass transit line was built in 2013, its transport system consisted of a large system of public buses and wagons (Figure 1). However, less than 5% of the working population took public transport to work (Figure 2); forty percent of working individuals walked to work, while most of the rest traveled by motorcycle (Figure 3). Ten percent of workers traveled to work by car. Highly educated workers were substantially more likely to commute by private transport: 80% of individuals with a university degree and 70% of those with a high school degree commute by private transport, while only half of those with less than a high school degree do so (Figure 4). In particular, the most educated workers are far more likely to commute by car (Figure 5).

The idea of a mass transit system had been floated in repeated urban planning documents since 1991, but without follow-up towards construction. In 2007, the military-led government, with assistance from the Japanese aid agency JICA, finalized a detailed mass transit plan with seven mass transit lines to cover most of the city and connect it to the edges of the peri-urban areas. The plan prepared by urban planning and transportation consultants included a sequence of lines to be built based on pre-existing patterns of transport use on each corridor (JICA, 2012). Figure 6 shows the entire plan. The full system as planned would cover most of the areas of population and employment in the city, even though firms in Lahore are not concentrated in a central business district (Figure 7).

In early 2008 democratic parties regained power in Pakistan, and the plan was shelved. However, in 2012, the democratic government, under pressure to complete public works in advance of an upcoming election, took up the plan again. It announced plans to build the first transit line recommended for construction in the plan, but to build it as a lower-cost Bus Rapid Transit line instead of a rail line. Building commenced rapidly and the Green Line was completed in early 2013, just before the spring 2013 election.

The Green Line crosses the entire city from north to south, covering a distance of about 26 km. It carries approximately 200,000 riders per day, approximately equivalent to 2% of the city's entire population. Like other Bus Rapid Transit systems, the Green Line comprises a system of buses running with a reserved lane to -allow high-speed transit. However, unlike some BRTs, this line incorporates extensive physical infrastructure in the form of dedicated overpasses. This feature was included in part to allow for new buses to run in addition to other vehicle traffic while minimizing land acquisition to widen the roadway in a congested city.

Overall the Green Line BRT is known to have a better quality of service than alternative buses in a number of ways. The buses run on a very high frequency and have less variability in arrival time due to the dedicated lane. In addition, stops have dedicated spaces which are protected from traffic, well lit, and have CCTV surveillance, unlike standard bus stops which are often no more than the side of the road without a sidewalk.

The fare was set at the level of 20 PKR (approximately 20 US cents) regardless of distance, while existing bus fares ranged from 15 to 45 PKR depending on distance. The line also reduced travel time from one end to the other from approximately 1.5 hours to 45 minutes. Hence the Green Line decreased travel time and costs substantially for many potential trips in the city.

The bus routes that overlapped with the mass transit line were cancelled along with its introduction. In addition, a number of bus routes were changed to act as feeder routes for the new transit line, but this occurred after our data were collected.

The government went on to announce plans in 2014 to build the second line recommended in the plan, the Orange Line, as a light-rail line, and began construction in 2015. Orange Line construction is ongoing. Our follow-up data were collected in 2015-2016, almost three years after the opening of the Green Line. As of early 2018, no time frame has been announced to build the other mass transit lines envisioned in the original plan. To allow for the possibility that the first two lines differ systematically from those planned for later years, which may not be built, we include estimates using *only* these first two lines as a robustness check on all our main estimates. These are included in all the main results tables (indicated as analysis on the subsample for T1 and T2 only).

3 Empirical strategy

Our causal estimates are based on comparing areas that are served by new transit with areas slated for potential routes that have not yet been built. This approach is arguably the most plausible identification strategy used in the literature (Redding and Turner, 2015); however, it requires the assumption that the order of lines to be built is uncorrelated with unobservables that affect the outcome variable. In this section, we outline how we improve on the basic strategy to relax the assumptions required. With matching and fixed effects, we require a much weaker assumption for identification of the causal effect of access to transit: areas that were both slated for a transit stop, both the same distance from the planned stop, and were similar on observables both twelve and three years before transit was built, should not differ on unobservables that affect our outcomes of interest.

Selection of priority areas for transit access based on unobservables such as political factors could be a concern when comparing built and unbuilt transit lines. However, the route plan used and sequence of lines built was the same as that developed under the technocratic military government, even after the change to a democratic multiparty system. This suggests that adjustments of the transit plan to target transit access on unobservables, such as neighborhoods well connected to politicians, did not take place at a small geographic scale. Rather, the government decided to move forward with a preexisting technical plan to serve the city as a whole. This is plausible given that the city as a whole is a stronghold of the ruling party, and that the government was keen to move forward without a lengthy planning process given the time pressure to complete construction before an election. Only one adjustment to the original route were made, in a busy central area of Lahore, to accommodate the above-ground bus design.[5] These areas are not a part of our sample. Thus it is reasonable to assume that the technical criteria for prioritizing the Green Line, in particular pre-existing transport patterns, were the deciding factor in the line sequencing.

3.1 Matching

To address the differences in lines on such observable factors, we use matching methods on the treated and control areas to select and sample data from areas which are similar before the first transit line was built.

While the Green Line was a high priority route, not all areas it connects would be high priority than those on the other planned lines. We select geographic areas among the areas served by these lines and the comparison lines that were similar before transit. The intuition is that after this selection, we identify areas that were not in themselves higher priority, but happened to be along a higher priority route. This allows us to address differences on a rich set of baseline observables between the built and unbuilt lines.

We matched on the level of a zone; Lahore has 228 zones, with populations ranging from 10 to

[5]The rail based plan was to be routed via Mall Road and Queen's road, whereas the BRT was aligned with Ferozpur Road instead to allow space for its dedicated lanes.

50,000. We use microdata from several sources for the matching. First, we use microdata from a 2010 survey of 18,000 households that the government gathered as a part of preparation of its urban master plan. This survey was sampled by the 228 urban zones and was designed to be representative of the entire metropolitan area. It includes household information, information on a roster of adult members, as well as a trip diary for each of these members.

In addition, we use block-level data from the 1998 census and microdata on industrial activity to select zones as follows. Incorporating data from both 1998 and 2010 in the matching procedure allows us to address the possibility of differential trends between the two groups.

Selecting zones near treatment and control lines Our objective is to select T1 areas, i.e. those that have access to the completed mass transit, the BRT or Green Line; T2 areas, those that would have access to the line under construction, the Orange Line, when it is completed, and control areas, those that would have access to the planned lines that have not been implemented.

All else equal, areas closer to a station are expected to be more affected by access to that station. However, to avoid measuring spillovers in our estimated treatment effect, control zones must be distant from T1 and T2 stops; similarly, T2 zones must be distant from T1 stops and vice versa. To ensure this, we selected an initial set of zones for analysis using distance from the planned and actual stations using successive radii as follows.

If the zone centroid was within X km of a control station station and was at least Y km from any T1 or T2 station, it was considered a control zone. Table 1 shows the full set of criteria used. So a zone that was within 2km of a control station and at least 3km from the nearest T1 or T2 station, it would be considered a control zone; or if it was within 3km of a control station and at least 4.5km from the nearest T1 or T2 station, it would be considered a control zone, and so on. Similarly, a zone would be considered a T1 zone if it was within 2km of a T1 station and at least 3km from the nearest T2 station; and vice versa.

Figure 8 shows the 121 zones selected according to this procedure. Note that areas in the center of the planned transit system, where all the lines interchange, are therefore excluded.

Despite this procedure, some degree of spillovers may still exist as a small number of commuters travel longer distances on another mode before boarding the mass transit line. This would attenuate a reduced-form treatment effect comparing treated and untreated areas. However, since we use distance to a stop on the built line as an instrument for a measure of public transport accessibility, these will account for such an effect on comparison zones (Angrist and Krueger, 2001).

Selecting a subset of comparable treatment and control zones Within each treatment group, we use a matching procedure to select zones that were similar on pre-treatment characteristics. We use a rich set of variables from 2012, which includes key aspects of the markets we study, including rental values, vehicle ownership, commute times, labor force participation, and wages, as well as more general characteristics. We also use the full set of educational and demographic variables available from the 1998 census. This is a more limited set of variables, but it allows us to identify zones that had similar time trends in these characteristics. The full set of variables used for matching is listed in Table 2.

To carry out the match, we construct the Mahalanobis distance on vector of baseline characteristics between each C zone and corresponding potential T1 zones:

$$D_M(x) = \sqrt{(x_i - x_j)' S^{-1} (x_i - x_j)}$$

Where

- x_i and x_j are vectors of baseline characteristics of a given control and T1 zone, respectively
- S is their covariance matrix

We then select pairs of C and T1 zones with $D_M \leq R$, where R is a fixed radius. Since the different sources of matching data have different units of observation, we calculate four different values of $D_{M,g}$, once for each group g of variables listed in Table 2 and set a radius R_g for each of them. To be selected as a match, a pair of zones must meet all the matching criteria, i.e. $D_{M,g} \leq R_g \forall g$.

We repeat the procedure for pairs of C and T2 zones. Finally, we select control group zones that have at least one matching T1 and one matching T2 zone. We allow multiple matches; this will be addressed in estimation using weights, as discussed below.

This final set of 50 zones, shown in Figure 9, is well-balanced in 2010 and 1998 (Tables 3 - 5). We select a representative sample of households from these zones for our household and community survey.

Weighting In some cases, a small control zone might be matched to a large T1 zone or vice versa. In addition, we allowed for multiple matches. In all specifications, we weight observations to correct for this, using the following procedure. Denote each control zone as $i \in 1...I$, and each T1 zone as $j \in 1...J$. Denote M_{ij} as an indicator equal to 1 if zones i and j were matched and zero otherwise.

We standardize the zone weight for control zones at 1 and calculate the zone weight for zone j as:

$$W_j = \sum_i \frac{M_{ij}}{\sum_j M_{ij}} \tag{1}$$

Thus the weight for each T1 zone increases in the number of control zones it is matched with, but decreases in the number of T1 zones that its counterpart control zones are matched to. We repeat the procedure for the T2 zones.

Then the weight applied to each household in zone g is defined as $\frac{W_g}{N_g}$, where N_g is the number of households sampled in zone g.

3.2 Distance fixed effects

To further relax the assumptions required for causal identification, we incorporate fixed effects for distance to the closest stop; each group has a 0.25km radius. This effectively compares households within a "doughnut ring" of this radius around a treatment stop to a similar ring around a stop on a planned line. In other words, the fixed effects estimate compares areas less than 1 km from a built stop with those less than 1km from a planned stop. Similarly, it compares areas 1-2km from a built stop with those 1-2km from a planned stop, and so on. This flexible specification allows the effect of distance from the planned stop on our outcome variables to take any functional form, rather than assuming it is linear.

3.3 Empirical specification

We use distance from a transit stop that was built as an instrument for public transport accessibility. Our measure of accessibility is the community respondent's report of the fastest travel time using only public transport to a central point in the city. The identifying assumption is that conditional on distance from any *planned* stop, distance from a *built* stop is exogenous.

We estimate the effects of new transit on outcomes Y_{ig} for individual or household i in geographic zone g:

$$ACCESS_g = \pi_1 + \pi_2 D1_g + \pi_3 D1_g^2 + \pi_4 D_g + \pi_5 D_g^2 + \alpha_d + \eta X_i + \upsilon_{ig} \tag{2}$$

$$Y_{ig} = \beta_1 + \beta_2 \widehat{ACCESS}_g + \beta_3 D_g + \beta_4 D_g^2 + \alpha_d + \gamma X_i + \epsilon_{ig} \tag{3}$$

Where $D1$ is the distance of the enumeration block from the closest built station and D is the distance from any planned station (whether built or not). α_d is a fixed effect for a distance "'doughnut ring", e.g. it is defined as 1 for all enumeration blocks that are between 1-2 km from either a built or unbuilt stop. All standard errors are clustered at the level of the zone (50 zones total).

Because transit stops in fact decreased both the financial and time cost of public transport travel to the center city, $ACCESS$ proxies for a change in both these costs.

For selected outcome variables, we also use recall data to construct a quasi-panel dataset, so that the assumption is further weakened to require only that such areas have parallel trends. This combination strategy ensures that the treatment group is comparable to the comparison group, so we can attribute differential changes to the introduction of the new transit.

We also test robustness to estimating Equation (2) including only areas served by the planned line and the line under construction. This helps to address the concern that selection of lines for shorter-term implementation may reflect differences between these areas (such as economic or political priority) that could be correlated with our outcomes of interest. The results of these estimations are shown in all main results tables (column 4, T1 T2 sample).

4 Data

4.1 Community and household survey in balanced sample

Within the balanced sample of zones we selected 550 random coordinates as sample points, using probability proportional to the population density in each area estimated from satellite imagery such that the data represent the population in the zone. At each point, an enumerator interviewed a real estate agent or other community member well informed about local real estate markets and local amenities. These respondents reported on local real estate purchase and rental prices for commercial and residential property for the current period (end 2015 / beginning 2016), the year before the Green Line was completed (2012), and three years before (2009). They also reported the typical travel time on different modes from that sample point to a well-known central point in Lahore (Kalma Chowk). Enumerators worked with these respondents to calculate the total time and cost of the best route from the survey sample point to the central point using only public transport (BRT, bus or wagon) and walking, at 9AM on a weekday (morning rush hour). This approach has the advantage of allowing for the actual frequency of public transport services, congestion and other real-world factors.[6] These are our main measure of travel time and cost on public transport.

The household survey included a total of 12,300 households. At each sample point, the survey team drew a random start direction and selected one every three households to interview. Response rates were approximately 70% and were balanced across treatment arms (Table **??**).

The survey included a roster of all household members age 15-65. For each such member, it covered work and commuting information. These variables were collected for the current period (end 2015 / beginning 2016) and the year before the Green Line was completed (2012). Respondents were also asked when the household moved into the area and whether each member had joined the household in the last three years, allowing us to identify in-migrants to the community. The survey also included questions on household characteristics including the household's vehicle ownership.

Women were often the main respondents, but in some cases did not have complete information on male family members' activities. Therefore we supplemented the respondents' reports with a shorter survey of a male household member which only covered confirmation or completion of records on male family members' employment. If the male was available at the time of the survey this was completed immediately afterwards; otherwise it was done by telephone after the field interview.

This allows us to collect a two- or three-period panel of key variables for households and adults; in the case of variables reported for 2009, this covers approximately 140,000 person-round observations. Table 7 shows that these recall baseline observations are also balanced across treatment arms.

Table 8 shows summary statistics for selected variables from the survey. The sample covers areas from 2-17 km from the central point of the city used as a reference point in our study (Kalma Chowk). About a third of the individuals in the sample work outside the home. Conditional on working, over two thirds commute by some motorized mode (i.e. they do not walk or bike to work) but only about seven percent commute via public transport. Overall, mean transport time is 24 minutes.

Because of the questions on new household members and how long the household has stayed in the area, we are able to identify in-migration to the residential area through a migration history. However, unlike a traditional panel, the data do not cover households that moved out of the area. Sixteen percent of households moved in to their current residence within the last three years, i.e. after the Green Line was built, demonstrating the importance of sorting as a potential mechanism. These

[6]These factors would likely be understated in a GIS trip analysis given that the frequency of public transport services is often not in line with the official schedule, and some routes that appear on official maps are sometimes not operated in practice.

households are excluded from our main estimates of interest. Table 25 shows analysis of differential sorting; overall, we see a small but statistically significant reduction in overall in-migration to treated areas, and those who move in are more likely to be young. However, we do not see any difference in the employment or commute history of those who move in to treated versus control areas.

4.2 Descriptive data sources

In addition to the 2015-6 survey of residential areas described above, we use two additional data sources for descriptive analysis. First, we use data from the 2010 HIS survey conducted by the government, described above.

Second, we conducted a survey of 2,500 riders on the BRT by approaching riders as they exited the station. We selected the start and end stations on the line and one every three stations in between, and randomly selected morning, mid day or afternoon shifts for interviews. We weight the estimates using administrative data on rider volumes provided by the Punjab Mass Transit Authority. Thus the survey data is representative of riders, other than those who ride in the early morning or late evening (before 8AM or after 6.30PM). Approximately two thirds of riders approached responded to the survey; in the case of non-response, enumerators recorded observable characteristics about the individual. Respondents were asked about their age and education, purpose and destination of their trip, the time and cost of the trip, their past travel behavior, and their hypothetical willingness to pay different prices for tickets on the BRT.

5 Results

5.1 Mass transit substantially improved public transport accessibility

Figure 16 shows the reduction in travel cost as reported by riders in our rider survey who report they took the same trip on other modes before 2012 (this makes up 70% of the sample). They report substantial decreases in travel cost. However, these data represent those who benefited from time and/or cost savings sufficiently high to switch to the BRT; they do not represent the effect on the population as a whole.

Figures 17 - 20 and Tables 11 - 12 show the effect of the new mass transit line on travel time and cost to central Lahore in our balanced sample of residential areas. The regression estimates represent the causal impact on the population in these sample areas. For every kilometer further from a mass transit stop, public transport accessibility decreases, with an increase of fare of 3.2 rupees (about 3.2 US cents) and an increase of time of 3.6 minutes. There are no such trends between the groups in the period preceding the introduction of the BRT (Table 22). We also estimate a similar specification in Table 13, with a binary for "treatment zones", showing that the average effect on the population of the sample zones is a 25-30 minute reduction in time, i.e. a decrease of about one third from the baseline mean of 76 minutes. The mass transit also reduced the public transport fare by 20-30 PKR, or over half the baseline mean. These figures represent a substantial improvement in public transport accessibility to an area including approximately 25% of the population of the city.[7]

The estimation shown in Table 11 is also the first stage for our IV specification (2), demonstrating that the instrument is informative. In our IV estimates, we use the time measure of public transport accessibility as the independent variable of interest. However, it proxies for overall public transport accessibility, representing both time and cost savings, since the mass transit expansion which is used as an instrument affects both time and cost savings.

Table 9 shows that in our balanced sample, distance to the closest built stop strongly predicts use of the BRT for commuting. For every kilometer further from a mass transit stop, the probability of commuting on the transit line decreases by 0.1 percentage points. The sample mean use is 1%, so this is a substantial gradient. Consistent with this, we also see an impact on the reported average commute time reported by commuters in the treated areas (Table 14).[8]

Since the BRT took over lanes in some areas of the city, some have voiced concern about additional congestion faced by commuters on private modes. The effects of a BRT are ambiguous, because it may shift some commuters into public transport, reducing congestion, but take lanes from private transport, increasing congestion. This has been a major issue in some settings, such as Delhi. However, in the case of Lahore, large sections of the BRT were built on overhead flyover, reducing the lane space required. We repeat our main estimates for the subset of individuals using private modes. These estimates should be taken with caution as they are subject to concerns of sample selection, since the mass transit treatment causes switching out of private transport. However, we find that the BRT reduced commute times reported by these individuals as well, suggestive of a reduction in congestion (table available on request).

[7]This figure includes the population of areas outside central Lahore which are accessible to the new mass transit, i.e. those shown in green in Figure 8.

[8]The mass transit line is known to be more frequent and reliable in service than the pre-existing bus services. We also measure variability in commute time in the survey by asking respondents the average commute time and how long it takes when traffic is busy. We do not see any impact of the BRT on this variable, but since it is reported by one respondent for multiple household members, the quality of data on the variability of commute time may be low.

Riders board from all parts of the line, but the heaviest traffic is at the endpoints (Figure 12). In addition, over half the riders travel on some other mode to reach the station and then change on to the Green Line (Figure 13). Figure 14 shows that about 80% of riders who walk to the station walk for 15 minutes or less to the station, suggesting a distance of under a mile given typical walking speed of 3 miles per hour. However, Figure 15 shows that about 30% of those who come by another vehicle traveled for more than half an hour to the station, suggesting that mass transit may have affected commute patterns for a larger catchment area than in the literature from the US. This is consistent with the high levels of congestion in Lahore; since these give mass transit a greater speed advantage over private vehicles, the catchment area in which it is optimal to take another mode to the mass transit line is larger (Baum-Snow and Kahn, 2000). However, note that our IV specification effectively addresses any use of the transit in zones selected for the control group, effectively readjusting the estimates for incomplete compliance (Angrist and Krueger, 2001).

5.2 Mass transit caused commuters to switch to public transport

The populations in areas slated for mass transit in the original plan (both our treatment and control areas) were higher income and more educated at baseline than the rest of the metropolitan area (Figure 10 - Figure 11). This likely reflects the fact that both the treated and control lines were routed on major thoroughfares, where mass transit was feasible and which are more desirable areas because of their overall accessibility. It does not necessarily reflect a deliberate attempt to target higher income populations. However, this pattern does differ from that found in the US: Baum-Snow and Kahn (2000) document that mass transit expansions have been systematically targeted towards lower income and less educated populations.

The targeting of public transport towards these higher-income and more educated populations is important because these individuals are the most likely to use private vehicles. This suggests a greater potential for mass transit to induce switching from private to public transit.

Figures 21 - 22 show the previous modes used by riders in our BRT rider survey who report they took the same trip before the mass transit line was built. Strikingly, 40% of the riders switched from using only private transport to public transport. The most common modes they report switching from are rickshaws and motorbikes, followed by cars. The respondents from the highest education brackets are more likely to report switching from a private mode (Figure 23).

Table 15 shows the causal estimates of public transport commuting on our comparable treated and control areas. Panel A shows the effects on all adults, while Panel B shows the effects on commuters.[9] Here the dependent variable is any use of public transport in the regular daily commute. This is defined as 1 for those who use public modes or a mixture of public and private modes (for example, taking a motorcycle to the mass transit station). The estimates imply that for every 10 minute improvement in public transport access (reduction in time it takes to reach a central point by public transport), the proportion of commuters who commute by public transport increases by 1.3 percentage points, an 18.5 percent increase from the baseline mean of 7%. Table 16 shows the equivalent estimates from a binary treatment specification: overall, mass transit increased the proportion of adults in treatment areas commuting by public transport by 1.5 percentage points; this is about 21% over the baseline mean or 30% over the control group.

We use the 2010 baseline data to get a total estimate based on extrapolating our estimates to all areas of the city, based on their access to the Green Line. Using this data, we generate predicted values for the change in use of public transport based on the reduced form version of our main estimates from the 2015 data (regressing public transport commuting directly on distance from the BRT stops and distance squared), and assuming zero effect beyond 10km from any stop. This calculation suggests that approximately 35,000 commuters would have switched from private to public transport across the city, assuming similar marginal effects of distance to transit in areas we did not sample. This is in the same order of magnitude as the descriptive statistics from the rider survey, which indicate that 40% of the BRT's riders who took the same trip in the past used private modes; since there are 200,000 riders and about 70% took the same trip in the past, this suggests approximately 56,000 switchers.

A switch to public transport could imply that commuters have switched from non-motorized modes such as walking or cycling to riding transit. Given that walking is the most common commute mode, this is a possibility in Lahore. While this would lead to time savings for commuters, such a switch would make the environmental impact of the mass transit ambiguous. However, we do not see a significant impact on use of motorized modes for commute (Table 17).[10]

Table 18 shows the impact on specific commute modes. The only mode-specific result that is robust across specifications is that on motorcycles: the switch to public transport appears to be driven by switching from this common, low-cost private mode. Table 19 shows the estimates for switching to

[9] We see no impact on whether an individual reports any commute (Table 24), addressing concerns about sample selection in the commuter sample.

[10] This is consistent with the fact that the mass transit line is generally considered more convenient for longer distance trips, because riders must climb several flights of stairs to reach the elevated platforms, so a substitution from walking to mass transit is less likely.

public transport stratified by whether the household owned any motorcycle at baseline. The estimates are similar between the two groups: while those who had no motorcycle would have switched from modes such as rickshaws to public transport, individuals who had the option of travel on a private motorcycle, which is convenient, fast and has a low marginal cost, also switched to public transport.[11]

5.3 Mass transit attracted higher status, more educated riders than previous public transport

The impact on vehicle owners points to a larger trend in the takeup of the mass transit line: riders come from a better-off households than the typical riders of buses before mass transit. As Figure 4 showed, more educated households were much more likely to take private modes at baseline. In contrast, the new mass transit line attracts riders with higher education levels. Figure 24 shows a comparison of the education levels of mass transit riders from the 2016 rider survey with that of riders of pre-existing buses in the 2010 HIS survey. For comparability, data from the subsample of the 2010 survey living in the zones slated for future mass transit are shown. These two data sources are collected differently, and are thus not fully comparable. Nevertheless, there appears to be a substantial difference in composition: only a quarter of baseline bus riders had a high school (Intermediate) degree or more, whereas 60% of mass transit riders have this level of education. Figure 23 shows that in the rider survey, more educated mass transit riders are slightly more likely to have switched from private transport modes. Table 21 shows that the causal effect of the mass transit line on the switch to public transport is similar for educated and less educated respondents Taken together, the descriptive and causal results on vehicle owners and educated respondents suggest that the mass transit line, with its high speed, quality and reliability, effectively attracted riders from a broader set of backgrounds, including many who could afford to take convenient, comfortable private commute modes. This indicates a shift towards commute patterns that can be more sustainable in the long run, even as economic growth allows more households to afford private vehicles.

5.4 Cost effectiveness and subsidy

In this section we consider both the time savings and potential environmental benefits of the imapacts on the shift to public transport, and compare them to available information about costs.

[11]While we find that the mass transit line has caused commuters to switch from private motorized transport to public transport, we find no impact on ownership of the most prevalent vehicle, motorcycles (Table 20). This may be explained by the short term of the impact, the fact that commuters on mass transit likely use motorbikes for trips to areas that mass transit does not reach, and that households often share vehicles.

To calculate a rough approximation the value of time saved for commuters, we estimate the total time savings for commuters in zones in both sampled and non-sampled areas, by estimating the predicted impact of the transit on the city-wide baseline data as described in 5.2. Multiplying this by each zone's commuting population at baseline and 528 one-way commute trips per person per year yields a total of 285,000 person work months of work. At the minimum wage of 13,000 PKR ($130) per month, this would add up to $37 million per year.

For a rough approximation of how the costs of the transit system translate into environmental benefits, we calculate approximate emissions averted as a result of the system. We start with the estimate of 35,000 individuals switching to public transit, discussed above, and the mode-wise results, which demonstrated that this switch is driven by a shift away from motorcycle use. We use these figures to calculate an approximate figure for emissions averted. Table 23 shows these calculations, which suggest that this switching would translate into a reduction of approximately 6,000 tons of CO2 per year.

These estimates are approximations, and cannot account for several factors. For example, there could be increases in the use of private transport from passengers from other parts of the city, taking advantage of decreased congestion; thus this would cause us to over-estimate emissions averted. On the other hand, they do not account for the effect of reduced congestion reducing the fuel burned for a trip of a given length, which would cause us to under-estimate the effect on emissions.

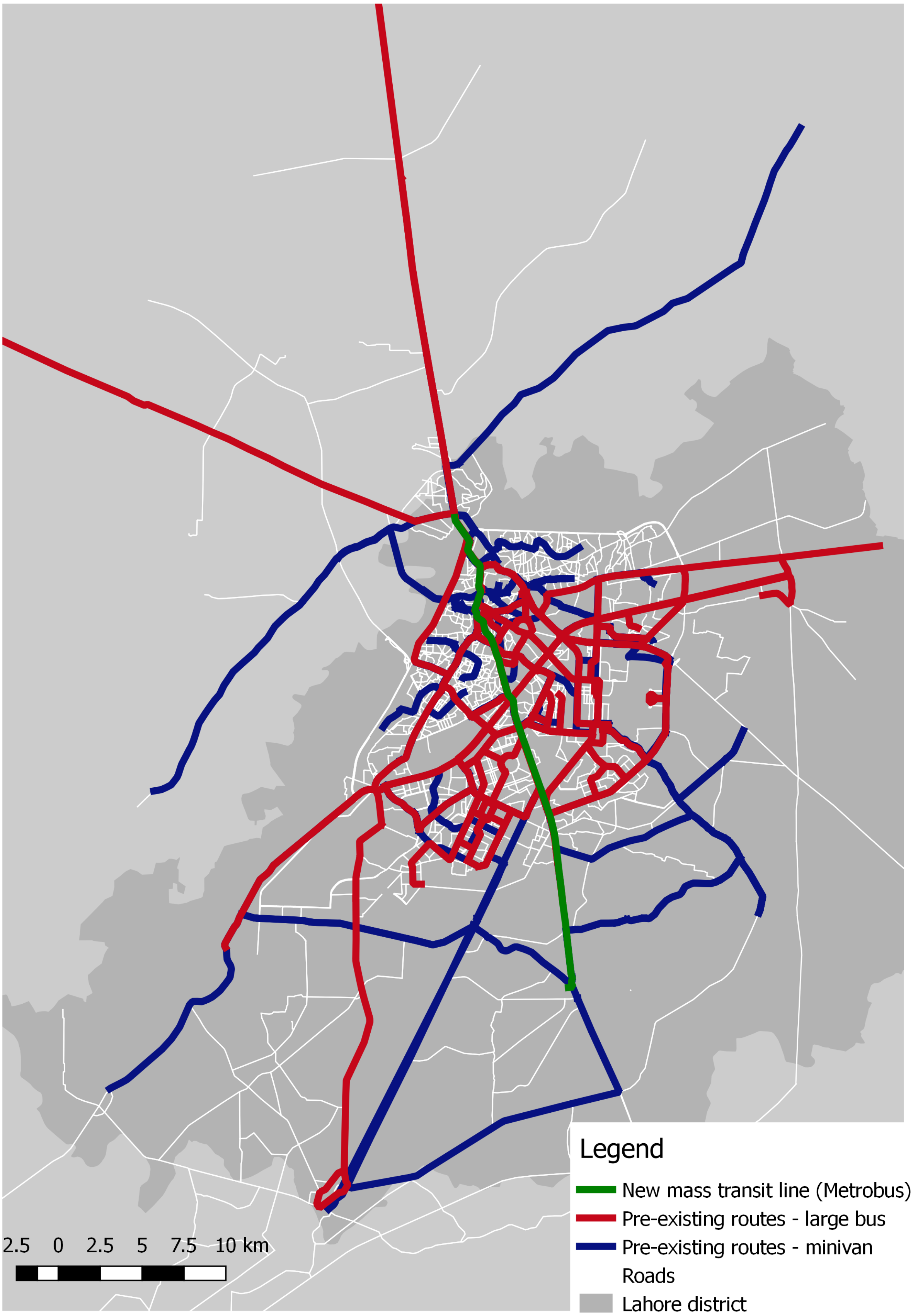
The official pre-construction estimate of the capital cost of the BRT mass transit line was 280 million USD, or 11 million USD per kilometer. This expenditure has been highly controversial, despite the fact that overall the majority of the province's transport budget is allocated for roads, with little spending on public transport (Malik, 2015). To date, we have been unable to obtain estimates of the actual incurred costs and running cost. However, if the estimates are accurate, this places Lahore's BRT at $11 million / km, on the high end of bus mass transit, compared to 5-10 million per km for similar systems in Turkey, China, India and Mexico City EMBARQ (2017). These systems are all far less expensive than (higher-capacity) light rail systems, which have capital costs in the range of $40-60 million per km.

The fare is set at 20 rupees (20 US cents) flat fare regardless of distance. On a monthly basis, this represents about 7% of the salary of a minimum wage worker, well below It is also substantially less for a long trip than a standard subsidized bus fare, which ranges up to 45 rupees depending on distance. Because the mass transit line is very heavily used, its total revenues may be more per vehicle than that of the buses. However, it is widely assumed that the system's operating costs are heavily subsidized. Given the cheap cost as well as the higher quality, it is not surprising that three-quarters of riders report they would be willing to pay a 50% higher fare for the same trip, and almost half say they are willing to pay double the current fare (Figure 25). Combined with the fact that mass transit riders include many commuters from higher socioeconomic backgrounds, this suggests that reducing or better targeting the subsidy could increase revenue with little loss of ridership, and the subsidy (on operating and perhaps even capital costs) could be defrayed. Given the logistical constraints, this could be achieved through peak pricing at the commute times common among office workers, which would alleviate congestion as well as targeting the lowest fares at blue-collar workers who typically work longer shifts and thus commute at earlier and later times. At peak times the buses run at completely full passenger loads; this has been an issue critiqued by opponents of the system, who argue it was built for short-term rather than long-term requirements. This suggests that increasing the fare at these times could be welfare enhancing and potentially even increase the total ridership, as passengers with greater schedule flexibility sort into off-peak times, reducing congestion effects.

6 Conclusion

The introduction of a new mass transit line in Lahore did not only reduce the time and money cost of commuting for those who already relied on public transport. It also caused a substantial proportion of commuters to switch to public transport, attracting educated workers who had private vehicles available as an option. While the existing system is subsidized, many commuters indicate they would still use it if the fare were increased substantially - reflecting its speed, quality and their higher average earning power than the population riding public buses in the past. These results suggest the potential of mass transit investments to create a substantial shift towards more sustainable urban commuting in the developing world.

Figure 1



Legend
New mass transit line (Metrobus)
Pre-existing routes - large bus
Pre-existing routes - minivan
Roads
Lahore district
2.5 0 2.5 5 7.5 10 km

Figure 2

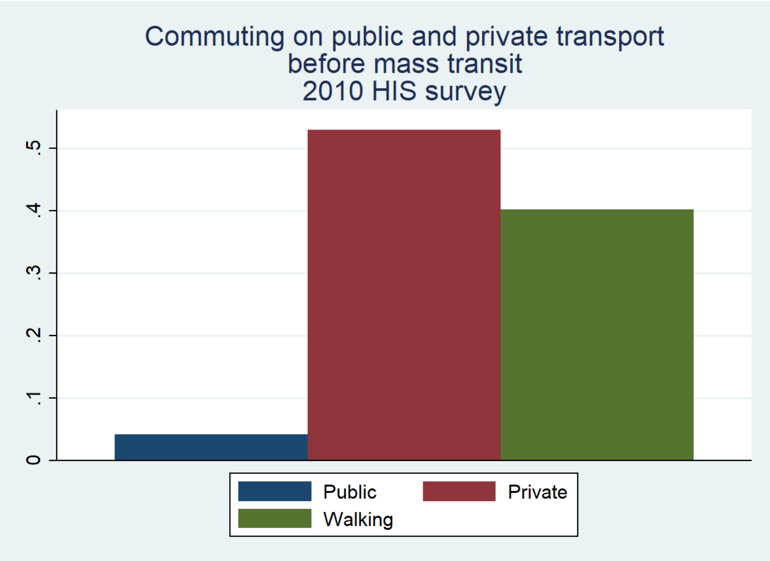


Figure 3

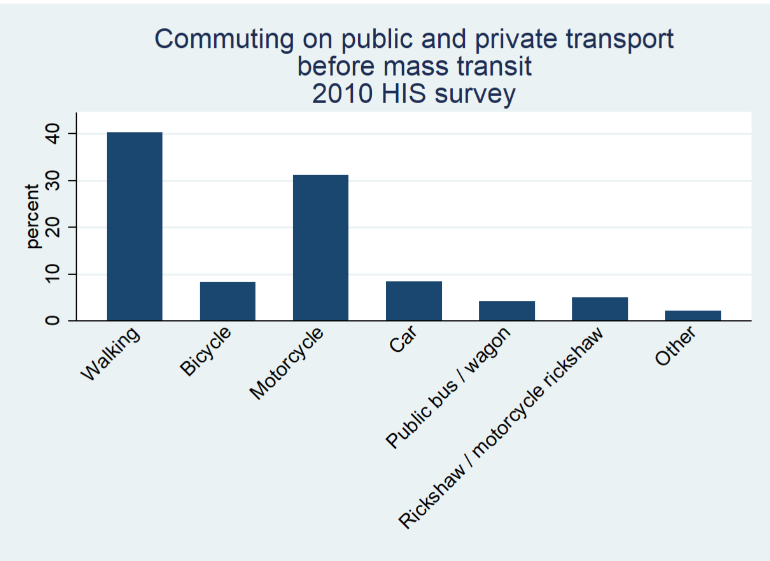


Figure 4

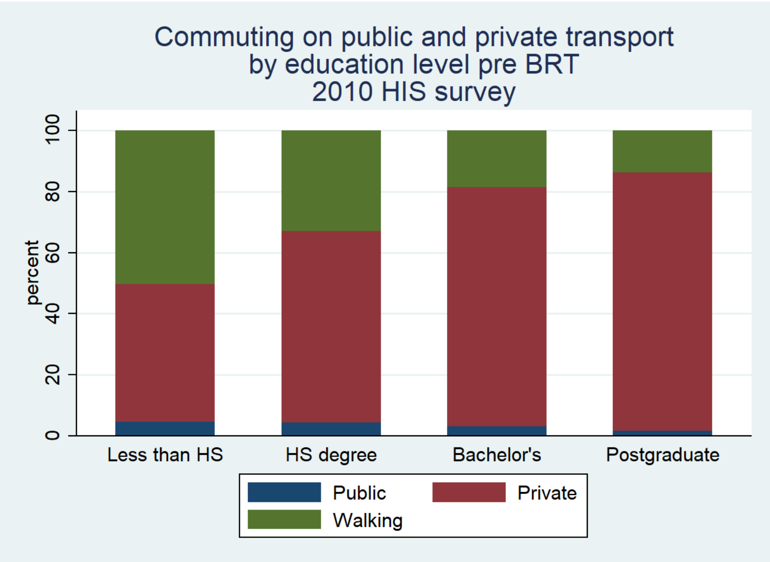


Figure 5

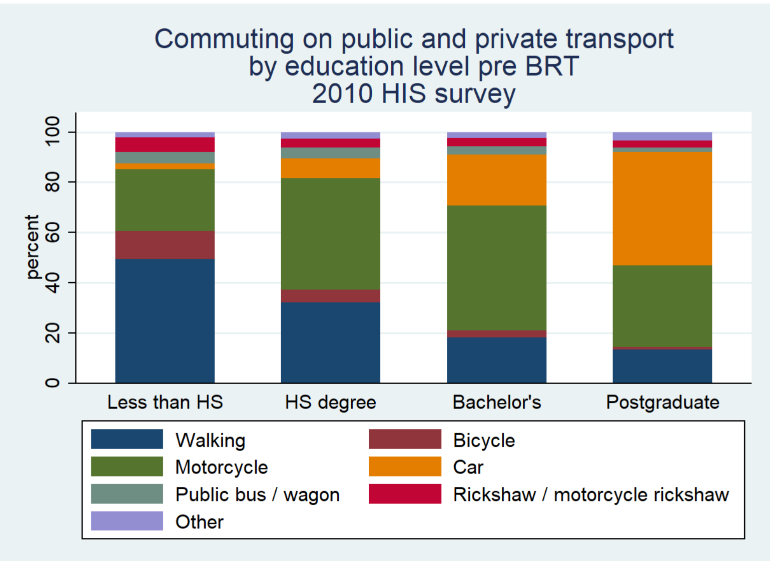


Figure 6

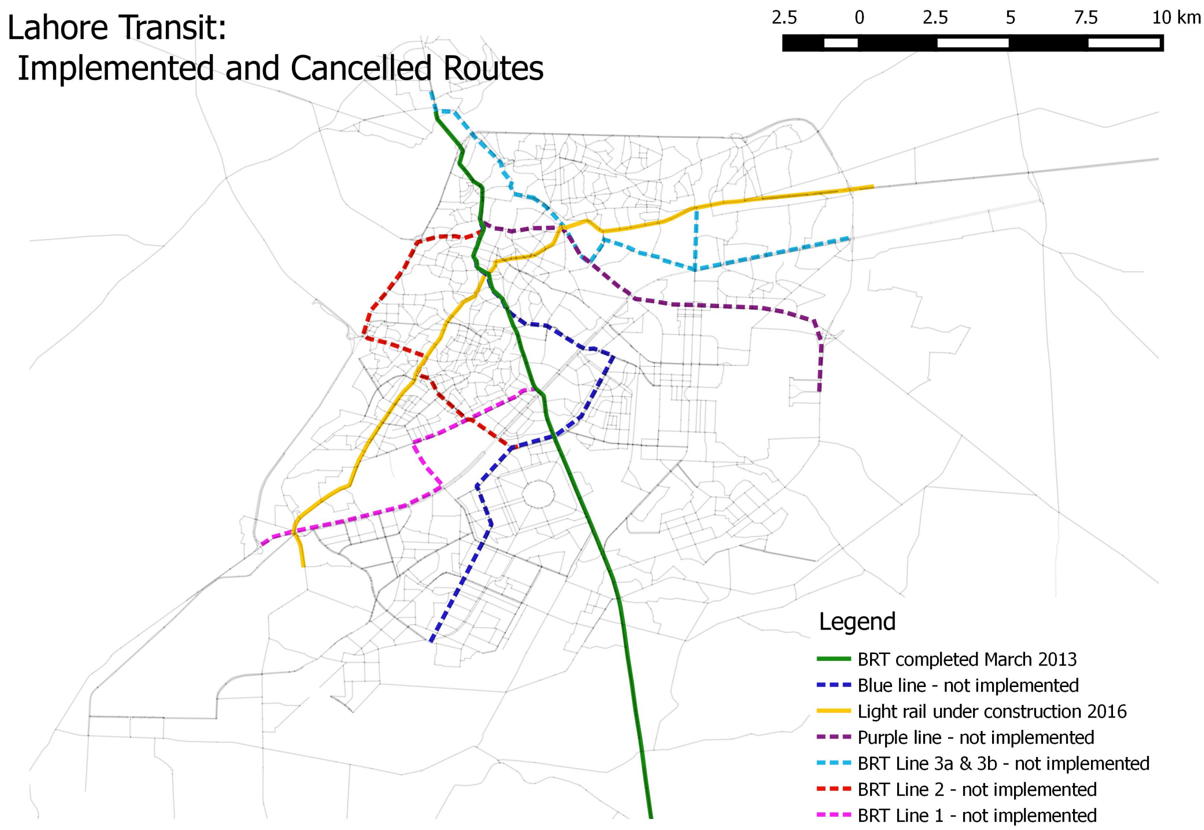

Lahore Transit:
Implemented and Cancelled Routes
2.5
0
2.5
5
7.5
10 km
Legend
BRT completed March 2013
Blue line - not implemented
Light rail under construction 2016
Purple line - not implemented
BRT Line 3a & 3b - not implemented
BRT Line 2 - not implemented
BRT Line 1 - not implemented

Figure 7

Notes: Red points represent the location of formal employers, identified from job advertisements in newspapers and web platforms.

Table 1: Radii used for selecting potential treatment and control zones and avoiding spillovers

To be assigned to treatment group i, Zone centroid must be:	
$<$ X km from a treatment i station	$\geq$ Y km from other $\geq$ treatment stations:
2	3
3	4.5
4	6
5	7.5
6	9
7	10.5

Figure 8

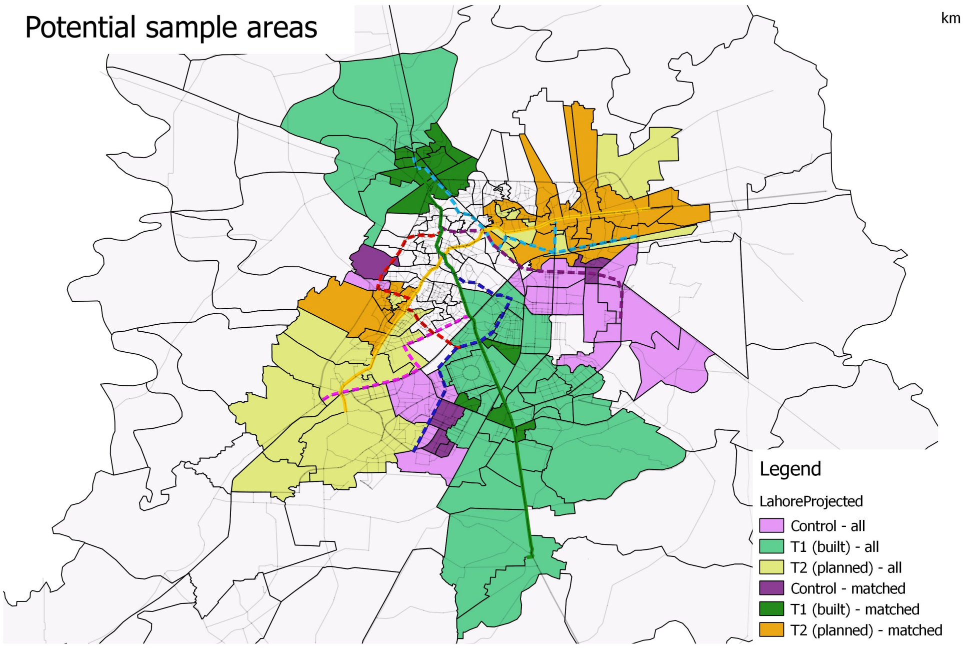


Table 2: Matching variables

Variable	Unit of observation
A. Masterplan zone-level data: Simple match on each variable	
Distance to center	Zone
Population density	Zone
B. Punjab Directory of Industries: Mahalanobis match group 1	
Number of manufacturing firms, weighted by (1 / distance from zone centroid)	Zone
Total firm investment, weighted by (1 / distance from zone centroid)	Zone
C. 1998 Census: Mahalanobis match group 2	
Proportion male completed primary education	Census block
Proportion female completed primary education	Census block
Proportion male completed matriculation	Census block
Proportion female completed matriculation	Census block
Proportion age 10 or older	Census block
Proportion age 18 or older	Census block
Proportion religious minorities	Census block
D. 2010 Lahore Masterplan Household Integrated Survey: Mahalanobis match group 3	
Any individual income	HH member
Level individual income	HH member
Log income	HH member
Education high school or less	HH member
Higher education	HH member
Trip cost in reference day	HH member
Trip duration in reference day	HH member
Years at location	Household
Owns house	Household
Rent paid per month	Household
House area	Household
Number of rooms	Household
HH income	Household
Monthly transport expenditure	Household
Bicycle ownership	Household
Motorcycle ownership	Household
Number of HH members living at HH	Household
Number of HH members living away from HH	Household
E. Neighboring zones: Mahalanobis match group 4	
All variables in Panel D, for all HHs in neighboring zones (centroids $\leq$ 3km)	HH / HH member

Figure 9

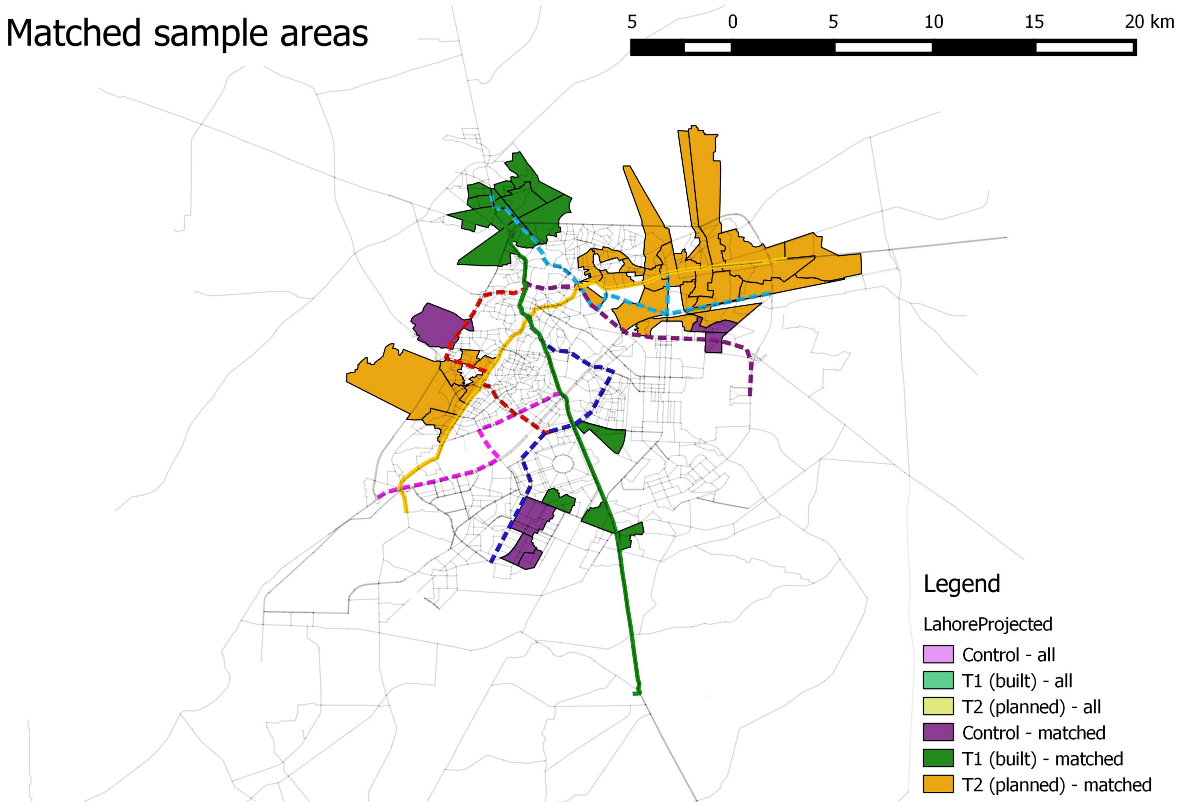

Matched sample areas
5 0 5 10 15 20 km
Legend
LahoreProjected
Control - all
T1 (built) - all
T2 (planned) - all
Control - matched
T1 (built) - matched
T2 (planned) - matched

Table 3: Balance after matching: 2010 HIS data

	T1 (line built)		T2 (line under construction)		
	Difference	SE	Difference	SE	Observations
Any income	0.00	(0.02)			6104
	0.00	(0.01)	-0.00	(0.01)	15140
Income	-282.09	(449.30)			6058
	-282.09	(442.91)	340.28	(324.10)	15049
Ln income	-0.06	(0.08)			2571
	-0.06	(0.08)	0.03	(0.07)	6347
Education: HS or less	0.05	(0.03)			6104
	0.05	(0.03)	0.01	(0.03)	15140
Education: HS	-0.01	(0.02)			6104
	-0.01	(0.02)	0.01	(0.01)	15140
Education: higher	-0.04	(0.03)			6104
	-0.04	(0.03)	-0.01	(0.02)	15140
Trip cost	-1.03	(3.22)			1934
	-1.03	(3.18)	0.73	(2.64)	4754
Trip duration	115758.12	(207783.54)			1910
	115758.12	(204824.59)	64206.64	(161151.79)	4701

Table 4: Balance after matching: 2010 HIS data

	T1 (line built)		T2 (line under construction)		
	Difference	SE	Difference	SE	Observations
Years at location	2.51	(2.47)			400
	2.51	(2.44)	4.75*	(2.43)	1012
Owns home	-0.03	(0.03)			394
	-0.03	(0.03)	-0.02	(0.03)	999
Rent expenditure per month	-259.83	(411.96)			400
	-259.83	(406.01)	-318.28	(383.56)	1012
House area	-1.93	(1.98)			398
	-1.93	(1.95)	-0.97	(1.94)	1005
Number of rooms	0.13	(0.32)			400
	0.13	(0.32)	0.40	(0.30)	1012
Transport expenditure	-125.14	(376.68)			399
	-125.14	(371.24)	69.23	(306.55)	1003
HH income	-0.23	(0.49)			400
	-0.23	(0.48)	0.24	(0.32)	1012
Bicycle	-0.05	(0.09)			400
	-0.05	(0.09)	0.02	(0.07)	1012
Motorcycle	-0.04	(0.08)			400
	-0.04	(0.08)	0.08	(0.06)	1012
Number of members living in HH	0.08	(0.23)			400
	0.08	(0.23)	0.15	(0.19)	1012
Number of members living away	0.03	(0.05)			400
	0.03	(0.05)	0.06	(0.04)	1012

Table 5: Balance after matching: 1998 census data

	Control group		T1 (Green line - built)		T2 (Orange line - under construction)	
	Mean	SE	Difference	SE	Difference	SE
Proportion with primary education - male	0.13	(0.01)	-0.01	(0.01)		
	0.13	(0.01)	-0.01	(0.01)	0.00	(0.01)
Proportion with primary education - female	0.11	(0.01)	-0.01	(0.01)		
	0.11	(0.01)	-0.01	(0.01)	0.01	(0.01)
Proportion with 10th grade education - male	0.10	(0.01)	-0.02	(0.02)		
	0.10	(0.01)	-0.02	(0.02)	0.01	(0.02)
Proportion with 10th grade education - female	0.07	(0.01)	-0.01	(0.01)		
	0.07	(0.01)	-0.01	(0.01)	0.01	(0.01)
Proportion age 10+	0.74	(0.01)	-0.02*	(0.01)		
	0.74	(0.01)	-0.02*	(0.01)	0.00	(0.01)
Proportion age 18+	0.54	(0.01)	-0.02	(0.01)		
	0.54	(0.01)	-0.02	(0.01)	0.00	(0.01)
Proportion non-Muslim	0.07	(0.02)	-0.02	(0.02)		
	0.07	(0.02)	-0.02	(0.02)	-0.03**	(0.02)

Table 6: Balance in response - primary survey

	Dependent variable: responds to survey	
	(1)	(2)
Distance to closest built stop (T1)	-0.0036	
	(0.0042)	
Distance to closest stop under construction (T2)	0.0046	
	(0.0041)	
Distance to closest planned stop (T1 / T2 / C)	0.0153	0.0148
	(0.0173)	(0.0171)
Treatment area (T1 - near built stop)		0.0508*
		(0.0302)
Area near stop under construction (T2)		-0.0094
		(0.0300)
Constant	0.7210***	0.7058***
	(0.0275)	(0.0210)
Observations	16851	16851

Table 7: Balance in recall baseline data - primary survey

Dependent variable: Recall 2012 commutes by public transport				
	(1)	(2)	(3)	(4)
Treatment area (T1 - near built stop)	0.0037	0.0027	-0.0003	0.0016
	(0.0029)	(0.0019)	(0.0042)	(0.0022)
Distance to closest planned stop (T1 / T2 / C)	0.0019	-0.0005	0.0019	-0.0003
	(0.0020)	(0.0013)	(0.0017)	(0.0013)
Area near stop under construction (T2)			-0.0077*	-0.0017
			(0.0039)	(0.0023)
Observations	30569	30184	30569	30184

Dependent variable: Recall 2012 commutes by public transport - conditional on commuting				
	(1)	(2)	(3)	(4)
Treatment area (T1 - near built stop)	0.0175	0.0103	-0.0005	0.0062
	(0.0150)	(0.0089)	(0.0218)	(0.0105)
Distance to closest planned stop (T1 / T2 / C)	0.0089	-0.0037	0.0091	-0.0031
	(0.0097)	(0.0054)	(0.0083)	(0.0053)
Area near stop under construction (T2)			-0.0357*	-0.0062
			(0.0205)	(0.0112)
Observations	6165	6100	6165	6100
Control variables	No	Yes	No	Yes
"Donut" FE	No	Yes	No	Yes

Each observation is one adult HH member in year 2012. Control variables include female, age, age squared, years of education and years of education squared. Standard errors clustered at the zone level. * p < .1, ** p < .05, *** p < .01.

Table 8: Summary statistics: Household Survey

Summary	(1)				
	count	mean	sd	min	max
Commute time	47395	7.965	15.99	0	360
Commute time (conditional on work)	16051	23.519	19.73	1	360
Motorized commute	48698	0.241	0.43	0	1
Motorized commute (conditional on work)	17251	0.678	0.47	0	1
Public transpport commute	48698	0.024	0.15	0	1
Public transport commute (conditional on work)	17251	0.067	0.25	0	1
Work outside	48663	0.356	0.48	0	1
Work outside (female)	23672	0.044	0.20	0	1
Distance to work - km	11814	17.555	9.37	.4402654	37.58378
Wage (PKR) - 5 pc winsorized	10159	16452.446	9630.02	4999.998	47040.01
gender	48779	1.485	0.50	1	2
Age	48779	34.932	14.93	17	85
Education	48181	7.526	5.45	0	18
dist_cent	48779	8.243	3.55	2.396217	17.01249
HH moved in during last 3 years	48338	0.163	0.37	0	1
HH moved in 4-6 years ago	48338	0.075	0.26	0	1
HH moved in more than 6 years ago	48338	0.762	0.43	0	1
Observations	48779				

	Zones	Sample points	Households	Individuals	Recall panel obs.
T1 (Green line - built)	15	188	6,152	24,295	72,885
T2 (Orange line - under construction)	29	256	3,902	15,304	45,912
C (Other planned lines)	6	86	2,447	9,180	45,912
Total	50	530	12,501	48,779	146,337

Notes: Recall panel observations are indicated for both 2009 and 2012; however, the set of recall variables collected for 2009 was limited, and did not include commute patterns.

Figure 10

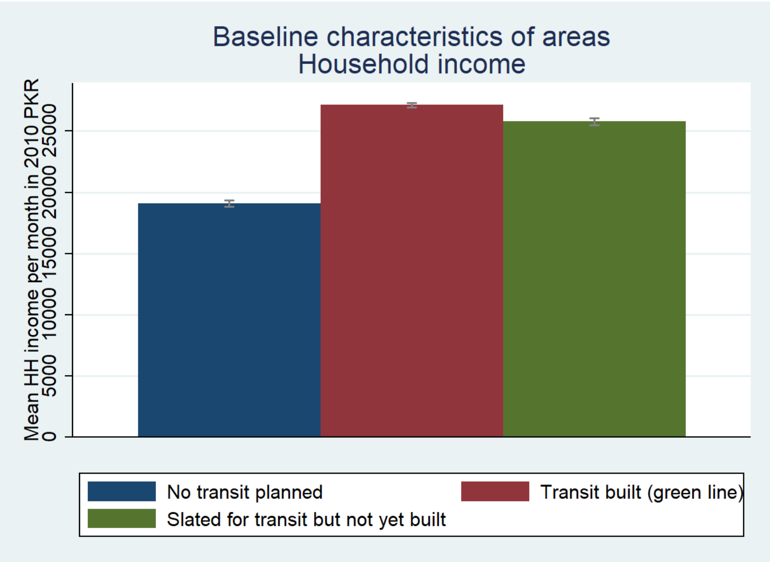


Figure 11

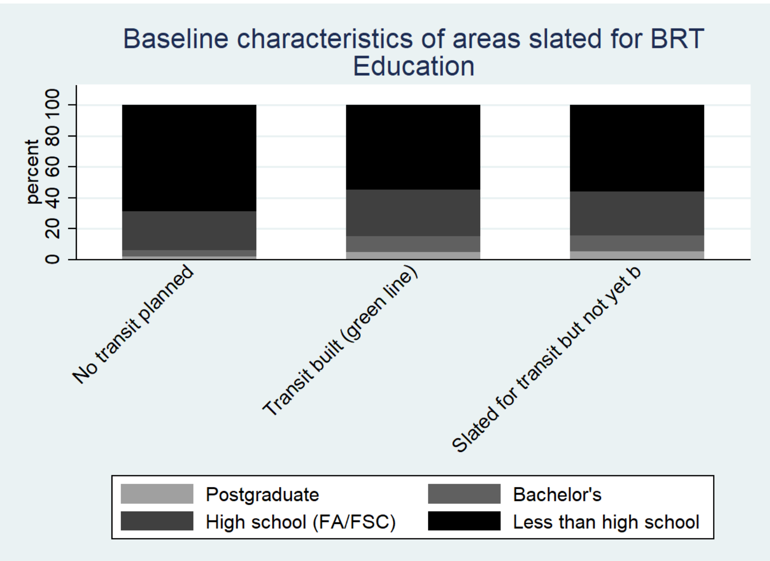
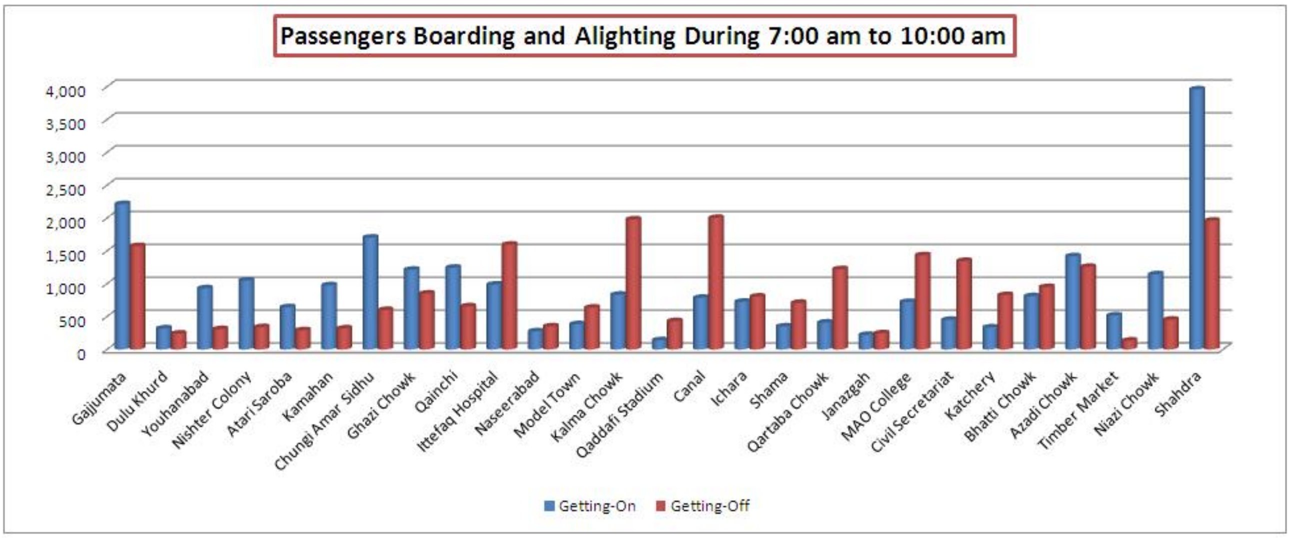


Figure 12: Administrative data: riders boarding and leaving BRT



Source: Punjab Mass Transit Authority

Figure 13

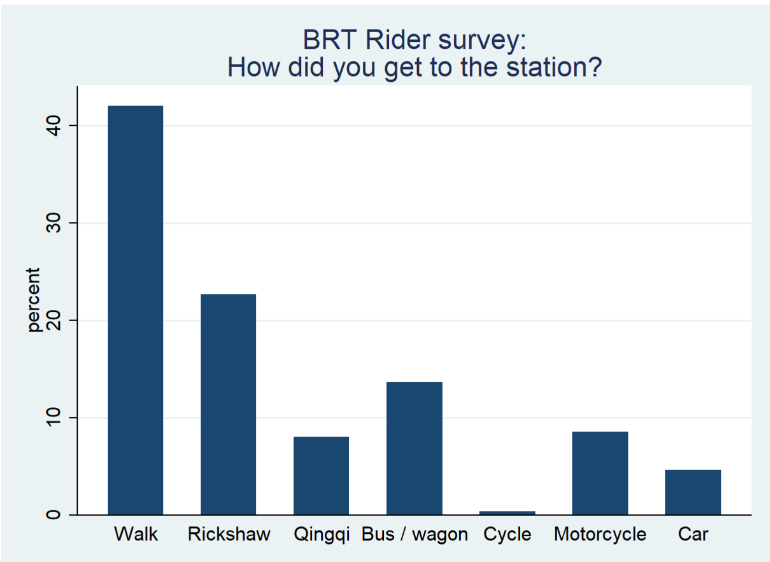


Figure 14

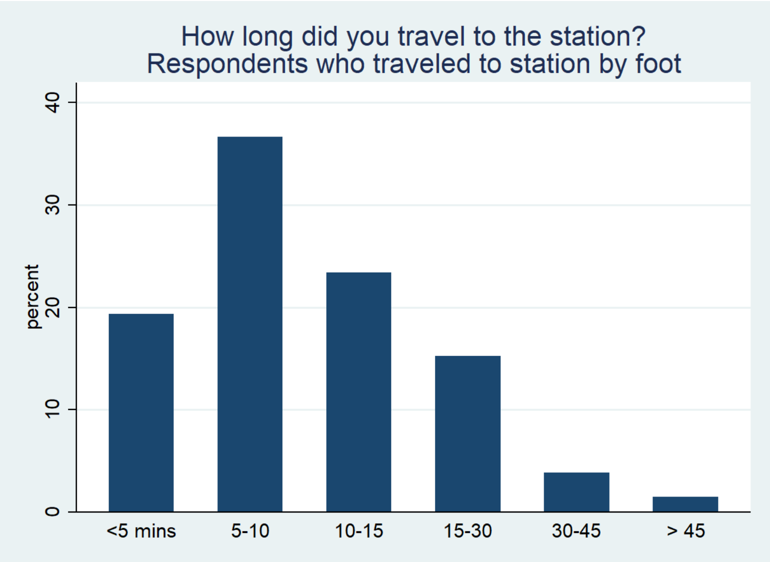


Figure 15

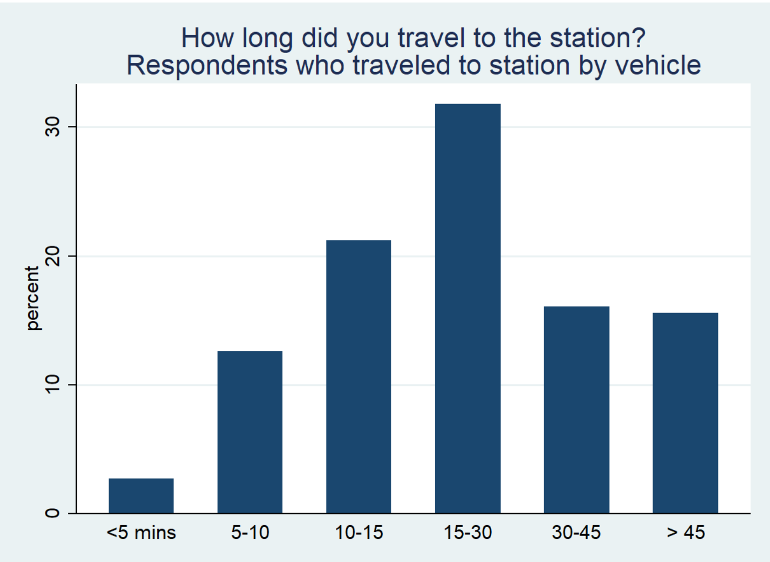


Figure 16

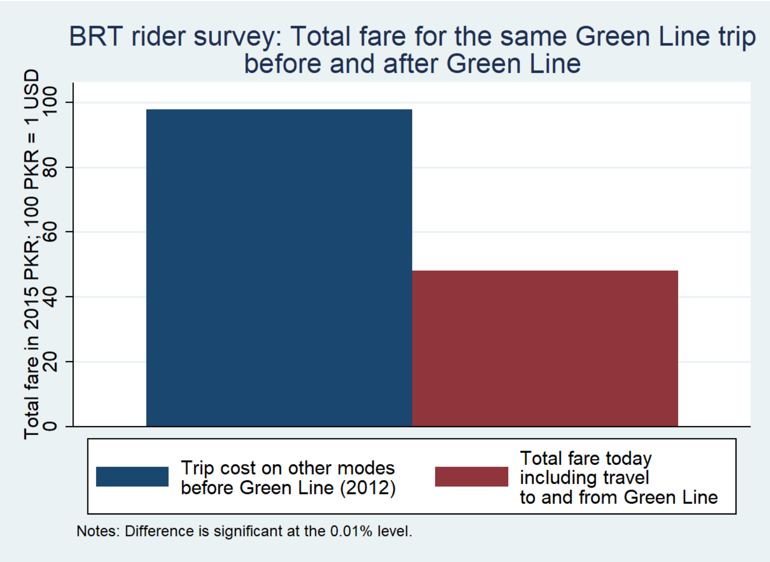


Figure 17

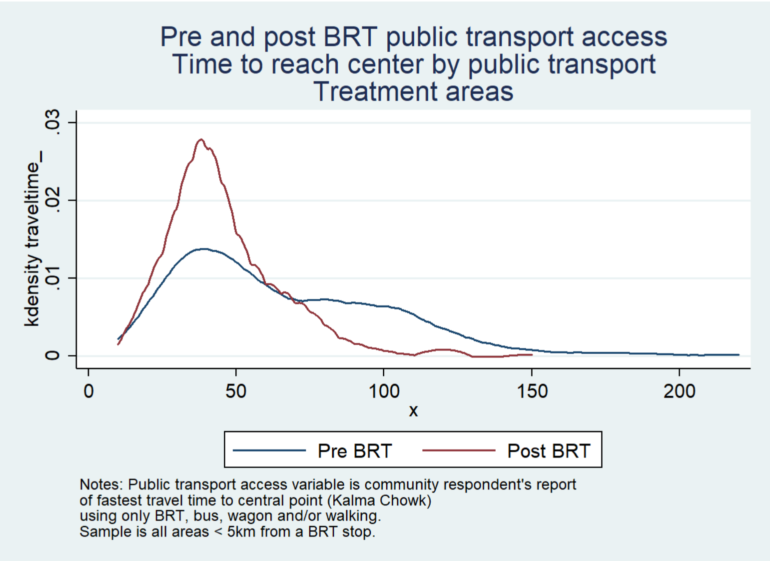


Figure 18

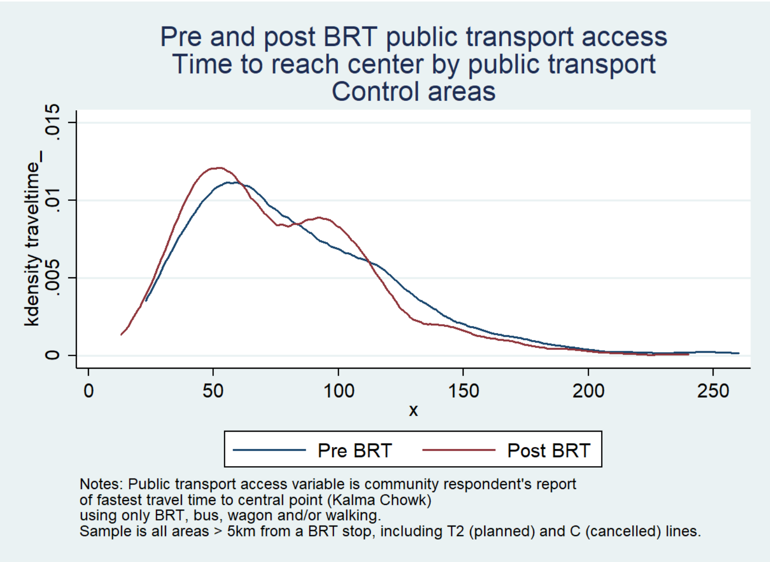


Figure 19

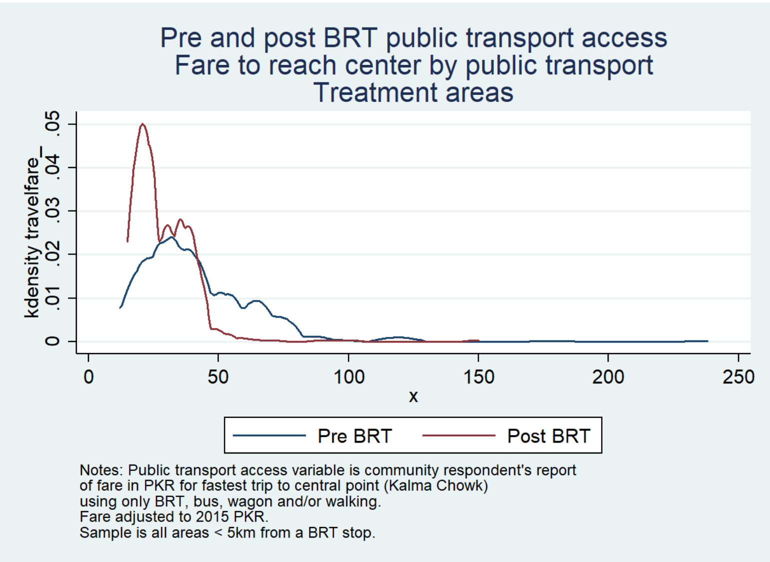


Figure 20

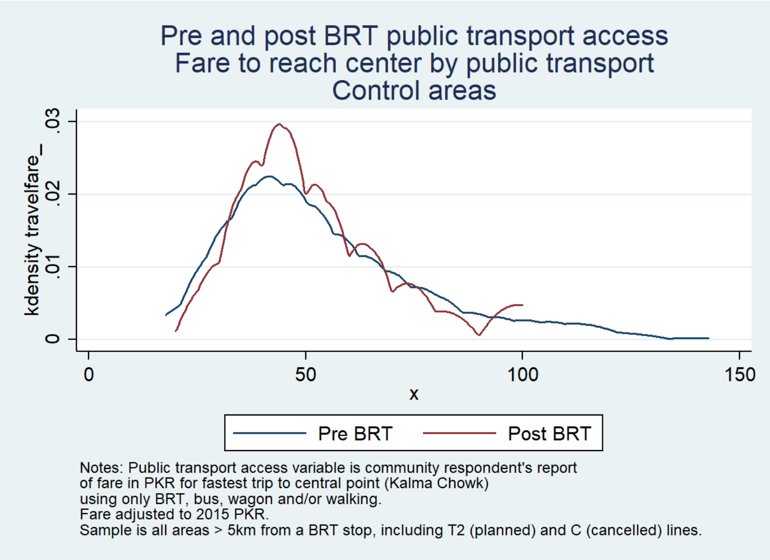


Table 9: Takeup of green line mass transit for daily work commute

	Dependent variable: rides mass transit for daily commute			
	(1)	(2)	(3)	(4)
Distance to closest built stop (T1)	-0.0014***	-0.0014***	-0.0031***	-0.0031***
	(0.0002)	(0.0002)	(0.0005)	(0.0005)
Distance to closest planned stop (T1 / T2 / C)	0.0010	0.0000	0.0004	0.0095
	(0.0006)	(0.0006)	(0.0013)	(0.0073)
Distance to closest built stop sq			0.0001***	0.0002***
			(0.0000)	(0.0000)
Distance to closest planned stop sq			-0.0001	-0.0010
			(0.0002)	(0.0008)
Constant	0.0104***	0.1464***	0.0470	
	(0.0017)	(0.0511)	(0.0536)	
Observations	48698	48107	48107	48107
Sample mean dependent variable				0.0100
Additional control variables	No	Yes	Yes	Yes
Donut ring FE	No	No	No	Yes

Each observation is one adult HH member in year 2015-6. Households and individuals who moved into their current residence after the Green Line was built are excluded. All specifications include controls for female, age, age squared, years of education and years of education squared. Standard errors clustered at the zone level. * p < .1, ** p < .05, *** p < .01.

Table 10: Impact of mass transit on commute times reported by commuters in HH survey

	Average one-way commute time				
	(1)	(2)	(3)	(4)	(5)
Time to access central Lahore through public transport	0.0174	0.0146*	0.0231**	0.0330***	0.0043
	(0.0109)	(0.0081)	(0.0101)	(0.0125)	(0.0109)
Observations	29870	29511	54549	44348	37718
Additional control variables	No	Yes	Yes	Yes	Yes
Donut FE	No	Yes	Yes	Yes	Yes
Geographic sample	Full	Full	Full	T1 T2	T1 C
Specification	XS	XS	Panel	Panel	Panel
Hansen's J p-value	0.6346	0.7012	0.0676	0.2755	0.1028
First-stage F-stat	11.5834	17.9282	20.1570	19.5775	34.9100
Sample mean pre	2.8300	2.8300	2.8300	2.5700	3.2100
	Average time, conditional on commuting				
	(1)	(2)	(3)	(4)	(5)
Time to access central Lahore through public transport	0.0447	0.0560*	0.1413**	0.1574**	0.0794**
	(0.0289)	(0.0305)	(0.0575)	(0.0665)	(0.0387)
Observations	6733	6665	8161	6501	5793
Additional control variables	No	Yes	Yes	Yes	Yes
Donut FE	No	Yes	Yes	Yes	Yes
Geographic sample	Full	Full	Full	T1 T2	T1 C
Specification	XS	XS	Panel	Panel	Panel
Hansen's J p-value	0.5908	0.6247	0.0252	0.0644	0.1116
First-stage F-stat	12.4734	19.3036	6.0310	6.8770	14.5648
Sample mean pre	23.1300	23.1300	23.1300	24.0600	22.8300

Each observation is one adult-round. Households and individuals who moved into their current residence after the Green Line was built are excluded. All specifications include controls for female, age, age squared, years of education and years of education squared. Standard errors clustered at the zone level. * $p < .1$, ** $p < .05$, *** $p < .01$.

Figure 21

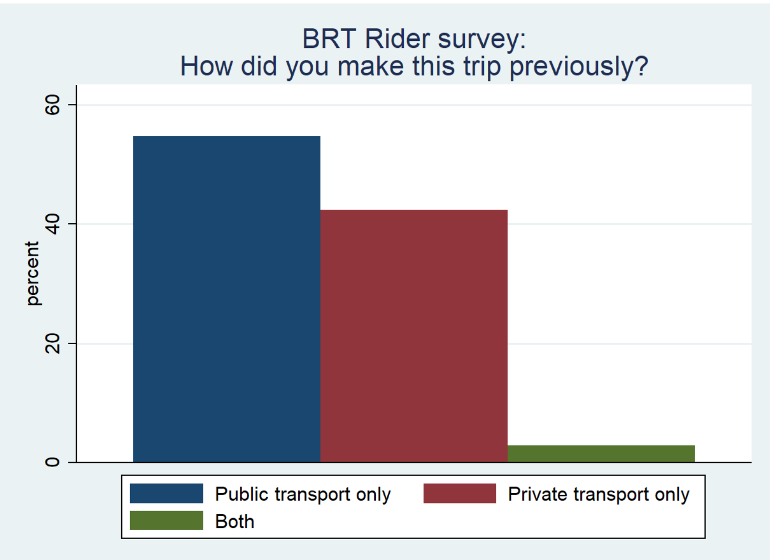


Table 11: Impact of transit on public transport access to center city - time (IV first stage)

	(1)	(2)	(3)	(4)
Distance to closest built stop (T1)	3.7183***	6.4400***	-2.0390	-1.5209
	(0.7348)	(2.1400)	(3.6423)	(3.7342)
Distance to closest planned stop (T1 / T2 / C)	4.1011	-0.2043	7.2752	16.3174
	(3.3562)	(6.3366)	(9.7785)	(26.7605)
Distance to closest built stop sq		-0.2113	0.2594	0.2132
		(0.1542)	(0.2401)	(0.2495)
Distance to closest planned stop sq		1.2400	0.5349	-0.9373
		(0.8871)	(1.3597)	(3.1685)
Post			-32.5280***	0.0000
			(6.9842)	(.)
Distance to closest built stop (T1) x post			8.4789***	8.5623***
			(2.0289)	(2.1067)
Distance to closest built stop sq x post			-0.4707***	-0.4795***
			(0.1201)	(0.1270)
Distance to closest planned stop x post			-7.4795	-5.0654
			(5.1617)	(15.1740)
Distance to closest planned stop sq x post			0.7051	0.3313
			(0.7385)	(1.7687)
Observations	515	515	1566	1566
Donut FE	No	No	No	Yes
Specification	XS	XS	Panel	Panel

Dependent variable is the real estate agent's report of travel time by public transport to central Lahore. Each observation is one sample point. Standard errors clustered at the zone level. * $p < .1$, ** $p < .05$, *** $p < .01$.

Figure 22

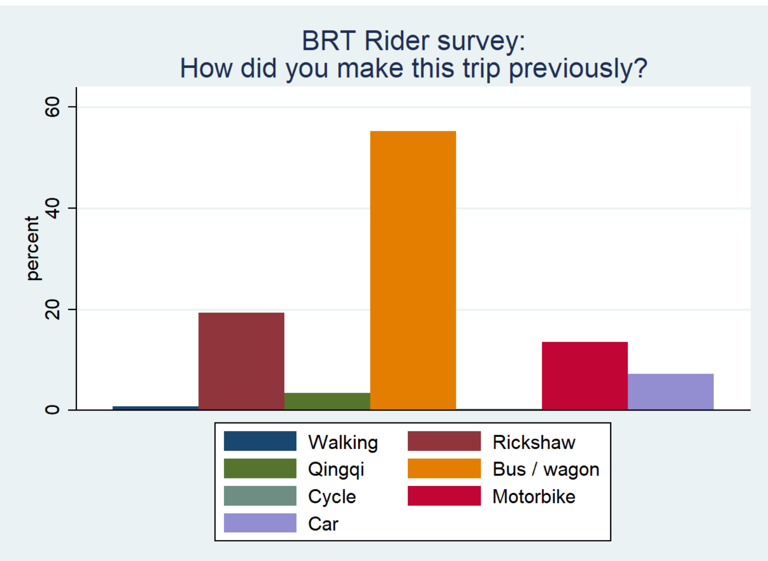


Table 12: Impact of transit on public transport access to center city - fare

	(1)	(2)	(3)	(4)
Distance to closest built stop (T1)	3.1304***	5.0346***	-1.8234	-1.7480
	(0.3663)	(0.7480)	(1.7282)	(1.7122)
Distance to closest planned stop (T1 / T2 / C)	-1.3240	-3.6768*	-3.2377	-8.2996
	(1.4352)	(1.9537)	(3.8572)	(12.3425)
Distance to closest built stop sq		-0.1475***	0.2022	0.1955
		(0.0545)	(0.1317)	(0.1304)
Distance to closest planned stop sq		0.6971**	0.5171	1.0657
		(0.2874)	(0.5201)	(1.5462)
Post			-18.0956***	0.0000
			(4.6394)	(.)
Distance to closest built stop (T1) x post			6.8581***	6.8880***
			(1.4690)	(1.4331)
Distance to closest built stop sq x post			-0.3497***	-0.3541***
			(0.1032)	(0.0954)
Distance to closest planned stop x post			-0.4391	27.9464***
			(3.6503)	(10.4085)
Distance to closest planned stop sq x post			0.1800	-3.0791**
			(0.4945)	(1.3096)
Observations	512	512	1550	1550
Donut FE	No	No	No	Yes
Specification	XS	XS	Panel	Panel

Dependent variable is the real estate agent's report of total fare for public transport to central Lahore. Each observation is one sample point. Standard errors clustered at the zone level. * p < .1, ** p < .05, *** p < .01.

Figure 23

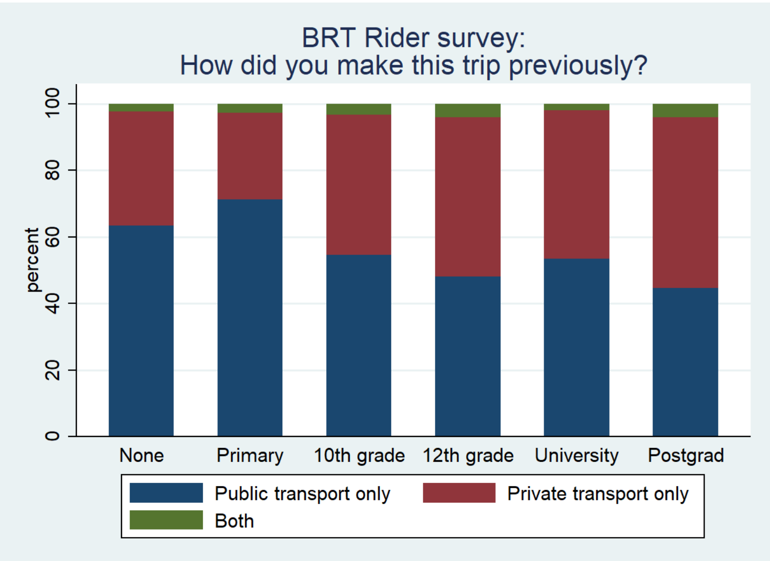


Table 13: Impact of transit on public transport access to center city - binary treatment variable

Dependent variable: time to reach central point by public transport			
	(1)	(2)	(3)
Treatment area (T1 - near built stop)	-23.3634***	4.9425	2.9882
	(6.6968)	(11.2001)	(11.1374)
Distance to closest planned stop (T1 / T2 / C)	8.2340**	9.7296**	10.1303***
	(3.3342)	(3.9788)	(3.3969)
Treatment area x post		-32.6565***	-26.0230***
		(6.4849)	(6.2909)
Distance to closest planned stop x post			-1.5104
			(1.8679)
Observations	521	1579	1579
Donut FE	No	No	Yes
Specification	XS	Panel	Panel
Baseline sample mean			76.3800

Dependent variable: fare to reach central point by public transport			
	(1)	(2)	(3)
Treatment area (T1 - near built stop)	-21.1993***	5.4052	4.4232
	(3.3119)	(7.2216)	(7.3772)
Distance to closest planned stop (T1 / T2 / C)	1.8879	0.3558	2.6949
	(1.5675)	(2.3948)	(1.6651)
Treatment area x post		-29.6241***	-25.3746***
		(5.7229)	(5.8236)
Distance to closest planned stop x post			2.1119
			(1.7304)
Observations	518	1563	1563
Donut FE	No	No	Yes
Specification	XS	Panel	Panel
Baseline sample mean			48.5900

Dependent variable is the real estate agent's report of total time or fare for a trip to a central point in Lahore (Kalma Chowk) using only public transport and walking. Each observation is one sample point. Standard errors clustered at the zone level. * p < .1, ** p < .05, *** p < .01.

Table 14: Impact of transit on respondents' commute times

Dependent variable: respondent's typical commute time			
	(1)	(2)	(3)
Time to access central Lahore by public transport	0.0416	0.0565*	0.0866*
	(0.0296)	(0.0289)	(0.0456)
Observations	6733	6665	5480
Donut FE	No	Yes	Yes
Geographic sample	Full	Full	T1 T2
Specification	XS	XS	XS
Hansen's J p-value	0.4161	0.6254	0.1583
First-stage F-stat	11.4724	20.3201	10.8722

Each observation is one adult in 2015. Households and individuals who moved into their current residence after the Green Line was built are excluded. The sample includes adults who report a commute only. The probability of commuting does not change (Table 24), so interpretation of the results conditional on commuting is not affected by sample selection concerns. Standard errors clustered at the zone level. * p < .1, ** p < .05, *** p < .01.

Table 15: Impact of transit on commuting by public transport

Commutes by public transport					
	(1)	(2)	(3)	(4)	(5)
Time to access central Lahore through public transport	-0.0004***	-0.0003***	-0.0001***	-0.0002***	-0.0001**
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0000)
Observations	30449	30071	59771	48786	41222
Additional control variables	No	Yes	Yes	Yes	Yes
Donut FE	No	Yes	Yes	Yes	Yes
Geographic sample	Full	Full	Full	T1 T2	T1 C
Specification	XS	XS	Panel	Panel	Panel
Hansen's J p-value	0.6455	0.7173	0.5121	0.3054	0.9483
First-stage F-stat	11.4762	18.0319	20.9746	20.4815	37.2840
Sample mean pre	0.0200	0.0200	0.0200	0.0200	0.0300
Commutes by public transport (conditional on commute)					
	(1)	(2)	(3)	(4)	(5)
Time to access central Lahore through public transport	-0.0017***	-0.0013***	-0.0005**	-0.0006*	-0.0004**
	(0.0005)	(0.0003)	(0.0002)	(0.0003)	(0.0002)
Observations	7261	7181	13182	10776	9141
Additional control variables	No	Yes	Yes	Yes	Yes
Donut FE	No	Yes	Yes	Yes	Yes
Geographic sample	Full	Full	Full	T1 T2	T1 C
Specification	XS	XS	Panel	Panel	Panel
Hansen's J p-value	0.9405	0.9949	0.2105	0.1921	0.8069
First-stage F-stat	11.9319	19.9707	20.0149	18.3624	39.0177
Sample mean pre	0.0700	0.0700	0.0700	0.0700	0.0800

Results shown for second stage of 2SLS estimate. Each observation is one adult-round. Households and individuals who moved into their current residence after the Green Line was built are excluded. The first panel shows estimations on the full sample, with observations taking on a zero value for adults who do not commute. The second panel shows estimations on the sample of adults who report a commute only. The probability of commuting does not change (Table 24), so interpretation of the results conditional on commuting is not affected by sample selection concerns. Standard errors clustered at the zone level. * p < .1, ** p < .05, *** p < .01.

Table 16: Impact of transit on commuting by public transport - binary specification

	Commutes by public transport (conditional on commute)	
	(1)	(2)
Treatment area (T1 - near built stop)	0.0299***	0.0133
	(0.0077)	(0.0087)
Treatment area x post		0.0150*
		(0.0082)
Observations	7205	13305
Control group mean		
Donut FE	Yes	Yes
Geographic sample	Full	Full
Specification	XS	Panel
Hansen's J p-value		
First-stage F-stat		

Results shown for second stage of 2SLS estimate. Each observation is one adult-round. Households and individuals who moved into their current residence after the Green Line was built are excluded. Estimations are conducted on the sample of adults who report a commute only. The probability of commuting does not change (Table 24), so interpretation of the results conditional on commuting is not affected by sample selection concerns. Standard errors clustered at the zone level. * p < .1, ** p < .05, *** p < .01.

Table 17: Impact of transit on commuting by motorized vehicle

	Commutes by motorized vehicle				
	(1)	(2)	(3)	(4)	(5)
Time to access central Lahore through public transport	0.0002	0.0001	0.0002**	0.0002**	0.0001
	(0.0002)	(0.0002)	(0.0001)	(0.0001)	(0.0001)
Observations	30449	30071	59771	48786	41222
Additional control variables	No	Yes	Yes	Yes	Yes
Donut FE	No	Yes	Yes	Yes	Yes
Geographic sample	Full	Full	Full	T1 T2	T1 C
Specification	XS	XS	Panel	Panel	Panel
Hansen's J p-value	0.0134	0.2964	0.8792	0.2905	0.0463
First-stage F-stat	11.4762	18.0319	20.9746	20.4815	37.2840
Sample mean pre	0.2200	0.2200	0.2200	0.2200	0.2200
	Commutes by motorized vehicle (conditional on commute)				
	(1)	(2)	(3)	(4)	(5)
Time to access central Lahore through public transport	0.0003	0.0006	0.0002	0.0002	0.0001
	(0.0010)	(0.0007)	(0.0004)	(0.0003)	(0.0004)
Observations	7261	7181	13182	10776	9141
Additional control variables	No	Yes	Yes	Yes	Yes
Donut FE	No	Yes	Yes	Yes	Yes
Geographic sample	Full	Full	Full	T1 T2	T1 C
Specification	XS	XS	Panel	Panel	Panel
Hansen's J p-value	0.0177	0.0081	0.6131	0.2478	0.3436
First-stage F-stat	11.9319	19.9707	20.0149	18.3624	39.0177
Sample mean pre	0.6800	0.6800	0.6800	0.6700	0.6700

Results shown for second stage of 2SLS estimate. Each observation is one adult-round. Households and individuals who moved into their current residence after the Green Line was built are excluded. The first panel shows estimations on the full sample, with observations taking on a zero value for adults who do not commute. The second panel shows estimations on the sample of adults who report a commute only. The probability of commuting does not change (Table 24), so interpretation of the results conditional on commuting is not affected by sample selection concerns. Standard errors clustered at the zone level. * p < .1, ** p < .05, *** p < .01.

Table 18: Impact of transit on substitute and complementary commute modes

	Bus				
Time to access central Lahore by public transport	-0.0001**	-0.0001**	0.0001*	0.0001**	0.0000
	(0.0001)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Observations	30487	30103	59846	48854	41270
	Van				
Time to access central Lahore by public transport	-0.0001**	-0.0000	0.0001**	0.0000	0.0001***
	(0.0000)	(0.0001)	(0.0000)	(0.0000)	(0.0000)
Observations	30487	30103	59846	48854	41270
	Rickshaw				
Time to access central Lahore by public transport	-0.0001	-0.0001	0.0001	0.0001*	-0.0000
	(0.0001)	(0.0002)	(0.0001)	(0.0001)	(0.0001)
Observations	30487	30103	59846	48854	41270
	Qingqi (motorcycle rickshaw)				
Time to access central Lahore by public transport	-0.0002	0.0001	0.0000	0.0002**	-0.0001*
	(0.0002)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Observations	30487	30103	59846	48854	41270
	Cycle				
Time to access central Lahore by public transport	0.0000	-0.0000	-0.0001***	-0.0000	-0.0001***
	(0.0001)	(0.0001)	(0.0000)	(0.0000)	(0.0000)
Observations	30487	30103	59846	48854	41270
	Walk				
Time to access central Lahore by public transport	-0.0007*	-0.0003	-0.0000	-0.0000	-0.0000
	(0.0004)	(0.0003)	(0.0001)	(0.0001)	(0.0001)
Observations	30487	30103	59846	48854	41270
	Motorcycle				
Time to access central Lahore by public transport	0.0006*	0.0004*	0.0003***	0.0003**	0.0003***
	(0.0003)	(0.0002)	(0.0001)	(0.0001)	(0.0001)
Observations	30487	30103	59846	48854	41270
	Car				
Time to access central Lahore by public transport	0.0000	-0.0002**	0.0000	0.0000	0.0000
	(0.0001)	(0.0001)	(0.0000)	(0.0000)	(0.0000)
Observations	30487	30103	59846	48854	41270
Controls	No	Yes	Yes	Yes	Yes
Donut FE	No	Yes	Yes	Yes	Yes
Geographic sample	Full	Full	Full	T1 T2	T1 C
Specification	XS	XS	Panel	Panel	Panel

Results shown for second stage of 2SLS estimate. Each observation is one adult-round. Households and individuals who moved into their current residence after the Green Line was built are excluded. All panels show estimations on the full sample, with observations taking on a zero value for adults who do not commute. Standard errors clustered at the zone level. * p < .1, ** p < .05, *** p < .01.

Table 19: Impact of transit on commuting by public transport: by vehicle ownership

	Dependent variable: Commutes by public transport (conditional on commute)				
	Sample: Households without a motorcycle at baseline				
	(1)	(2)	(3)	(4)	(5)
Time to access central Lahore by public transport	-0.0019***	-0.0013*	-0.0008	-0.0011*	-0.0006
	(0.0007)	(0.0008)	(0.0005)	(0.0006)	(0.0005)
Observations	2094	2071	3733	3184	2718
Subsample					
Donut FE	No	Yes	Yes	Yes	Yes
Gegraphic sample	Full	Full	Full	T1 T2	T1 C
Specification	XS	XS	Panel	Panel	Panel
Hansen's J p-value	0.7544	0.9414	0.0544	0.0317	0.6091
First-stage F-stat	12.4989	24.9647	19.7721	20.7741	27.4555
Control group mean					
	Sample: Households with at least 1 motorcycle at baseline				
	(1)	(2)	(3)	(4)	(5)
Time to access central Lahore by public transport	-0.0016***	-0.0012***	-0.0003	-0.0004	-0.0003*
	(0.0004)	(0.0004)	(0.0002)	(0.0003)	(0.0002)
Observations	5167	5110	9449	7592	6423
Subsample					
Donut FE	No	Yes	Yes	Yes	Yes
Geographic sample	Full	Full	Full	T1 T2	T1 C
Specification	XS	XS	Panel	Panel	Panel
Hansen's J p-value	0.9543	0.7117	0.6352	0.8525	0.7882
First-stage F-stat	12.1931	17.4131	19.3378	17.3892	44.8293
Control group mean					

Results shown for second stage of 2SLS estimate. Each observation is one adult-round. Households and individuals who moved into their current residence after the Green Line was built are excluded. Both panels show estimates for the subsample of adults who report a commute. The probability of commuting does not change (Table 24), so interpretation of the results conditional on commuting is not affected by sample selection concerns. Standard errors clustered at the zone level. * $p < .1$, ** $p < .05$, *** $p < .01$.

Table 20: Impact of transit on vehicle ownership

	Dependent variable: motorcycles owned by HH				
	(1)	(2)	(3)	(4)	(5)
Time to access central Lahore through public transport	0.0025	-0.0005	-0.0004	0.0003	-0.0014
	(0.0025)	(0.0019)	(0.0013)	(0.0019)	(0.0012)
Observations	2347	2326	4634	3772	3186
Additional control variables	No	Yes	Yes	Yes	Yes
Donut FE	No	Yes	Yes	Yes	Yes
Geographic sample	Full	Full	Full	T1 T2	T1 C
Specification	XS	XS	Panel	Panel	Panel
Hansen's J p-value	0.3269	0.9164	0.4008	0.8401	0.3244
First-stage F-stat	11.2245	15.9859	18.9385	18.3329	29.8714
Sample mean pre	0.8100	0.8100	0.8100	0.8000	0.7800

Results shown for second stage of 2SLS estimate. Each observation is one household-round. Households and individuals who moved into their current residence after the Green Line was built are excluded. Standard errors clustered at the zone level. * $p < .1$, ** $p < .05$, *** $p < .01$.

Figure 24

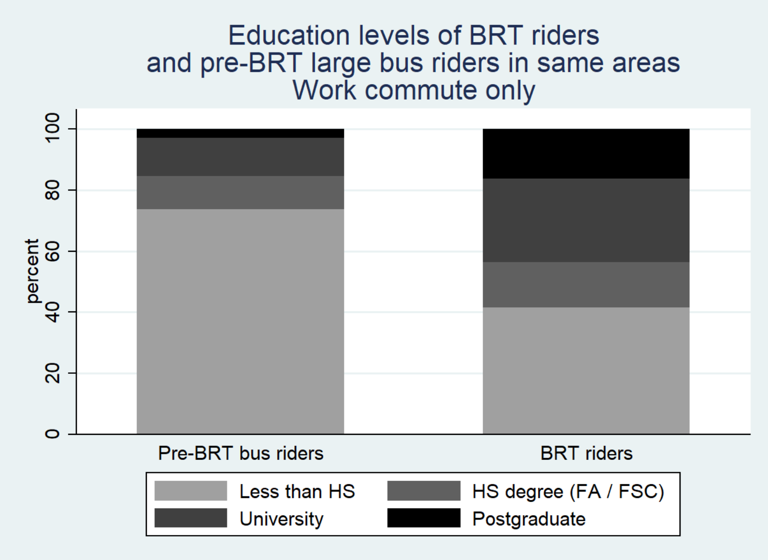


Table 21: Impact of transit on commuting by public transport: by education

	Dependent variable: Commutes by public transport (conditional on commute)				
	Sample: Less educated (Middle school or lower)				
	(1)	(2)	(3)	(4)	(5)
Time to access central Lahore by public transport	-0.0014***	-0.0012***	-0.0005	-0.0004	-0.0006*
	(0.0004)	(0.0004)	(0.0003)	(0.0004)	(0.0003)
Observations	3589	3509	6548	5496	4696
Subsample					
Donut FE	No	Yes	Yes	Yes	Yes
Gegraphic sample	Full	Full	Full	T1 T2	T1 C
Specification	XS	XS	Panel	Panel	Panel
Hansen's J p-value	0.2422	0.1141	0.1542	0.2541	0.4819
First-stage F-stat	13.1701	22.5165	21.5417	19.0915	43.2047
Control group mean					
	Sample: More educated (Matric degree (10th grade) or higher)				
	(1)	(2)	(3)	(4)	(5)
Time to access central Lahore by public transport	-0.0019***	-0.0016***	-0.0005	-0.0006	-0.0004
	(0.0006)	(0.0004)	(0.0003)	(0.0004)	(0.0002)
Observations	3672	3672	6634	5280	4445
Subsample					
Donut FE	No	Yes	Yes	Yes	Yes
Geographic sample	Full	Full	Full	T1 T2	T1 C
Specification	XS	XS	Panel	Panel	Panel
Hansen's J p-value	0.2769	0.4420	0.7737	0.7379	0.8402
First-stage F-stat	9.7189	15.6137	17.7496	16.3930	33.8496
Control group mean					

Results shown for second stage of 2SLS estimate. Each observation is one adult-round. Households and individuals who moved into their current residence after the Green Line was built are excluded. Both panels show estimates for the subsample of adults who report a commute. The probability of commuting does not change (Table 24), so interpretation of the results conditional on commuting is not affected by sample selection concerns. Standard errors clustered at the zone level. * p < .1, ** p < .05, *** p < .01.

Table 22: Test for differential pre-trends

	Time to access central Lahore by public transport		Cost to access central Lahore by public transport	
	(1)	(2)	(3)	(4)
Distance to closest built stop (T1)	-1.9755	-1.5793	-3.1987	-3.1913
	(3.7488)	(3.8358)	(2.9118)	(2.8498)
Distance to closest built stop sq	0.2489	0.2104	0.3407	0.3396
	(0.2530)	(0.2607)	(0.2332)	(0.2279)
Distance to closest planned stop (T1 / T2 / C)	8.7390	4.8860	-8.1325	-18.0231
	(9.8404)	(24.1312)	(6.7773)	(13.8922)
Distance to closest planned stop sq	0.2801	0.3442	1.4355	2.5439
	(1.3806)	(2.8507)	(0.9459)	(1.8190)
Year 2012	2.5956	2.5179	-13.9314***	-14.0641***
	(2.6692)	(2.7542)	(3.2461)	(3.2526)
Distance to closest built stop x 2012	-0.2354	-0.1970	1.1730	1.2353
	(0.7215)	(0.7453)	(1.0971)	(1.0790)
Distance to closest built stop sq x 2012	0.0235	0.0219	-0.1010	-0.1058
	(0.0515)	(0.0518)	(0.0990)	(0.0966)
Distance to closest planned stop x 2012	-2.6517	-2.8990	3.7800	3.6069
	(2.3418)	(2.3982)	(2.8450)	(2.8783)
Distance to closest planned stop sq x 2012	0.3657	0.4142	-0.9452**	-0.9114**
	(0.3597)	(0.3726)	(0.4452)	(0.4521)
Constant	66.0093***		66.0228***	
	(12.5741)		(9.0504)	
Observations	1042	1042	1029	1029
Donut FE	No	Yes	No	Yes

Standard errors clustered at the zone level. * p < .1, ** p < .05, *** p < .01.

Figure 25: Rider self-reported willingness to pay higher fares for mass transit

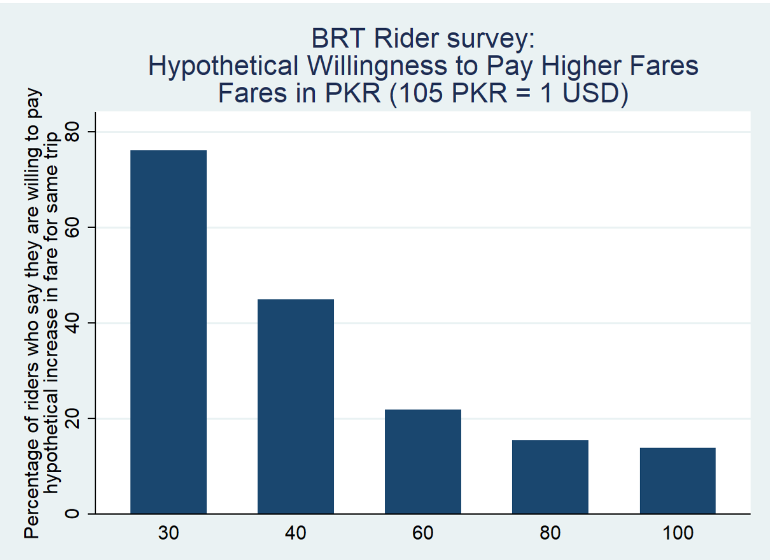


Table 23: Approximate calculations of averted emissions from switching to public transport

	Parameter	Estimate	Source
a	Bus - miles per gallon	3.4	US DOE
b	Bus - passengers per vehicle	50	Assumption
c	Bus - passenger miles per gallon	170	a * b
d	Motorcycle - miles per gallon	42	US DOE
e	Motorcycle - passengers per vehicle	1.5	Assumption
f	Motorcycle - passenger miles per gallon	63	d * e
g	Number of switchers	35000	HH survey regression estimates*
h	Mean travel distance (daily round trip)	9	Baseline HH survey (2010 HIS)
i	Proportion switching completely to public transport	0.55	Descriptive data from rider survey
j	Proportion of trip on private modes for mixed mode trips	0.5	Assumption
k	Gallons gasoline equivalent averted		
	per mile traveled on bus instead of motorcycle	0.01	(1/f) - (1 / c)
l	Passenger-miles traveled on bus instead of motorcycle	228375	(1 - i*j) * g * h
m	Gallons gasoline equivalent averted - total	2,282	k*l
n	Grams CO2 per gallon gasoline equivalent	8,837	US EPA
o	Tons CO2 averted per working day	22	m*n / 900,000 grams / ton
p	Tons CO2 averted per year	5,914	o * 264 working days

Notes: Fuel economy data are based on data in US Department of Energy (2017).

Table 24: Impact of transit on probability of commuting to work

	(1)	(2)	(3)	(4)	(5)
Time to access central Lahore through public transport	0.0001	0.0000	0.0002	0.0002	0.0001
	(0.0003)	(0.0003)	(0.0001)	(0.0001)	(0.0001)
Observations	30423	30052	59637	48684	41110
Additional control variables	No	Yes	Yes	Yes	Yes
Donut FE	No	Yes	Yes	Yes	Yes
Geographic sample	Full	Full	Full	T1 T2	T1 C
Specification	XS	XS	Panel	Panel	Panel
Hansen's J p-value	0.8600	0.5173	0.2801	0.9404	0.0363
First-stage F-stat	11.4554	18.1063	20.9745	20.5628	37.1704
Sample mean pre	0.3300	0.3300	0.3300	0.3300	0.3400

Results shown for second stage of 2SLS estimate. Each observation is one adult-round. Households and individuals who moved into their current residence after the Green Line was built are excluded. Standard errors clustered at the zone level. * $p < .1$, ** $p < .05$, *** $p < .01$.

Table 25: Migration and sorting

	In-migrant	Female	Age	Years ed home	Work outside home (females)	Work outside commute	Vehicle commute	Public	Ln wage
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Time to access central Lahore by public transport	0.0010**	0.0002	0.0247**	0.0166	0.0003	-0.0000	0.0005	-0.0000	0.0001
	(0.0005)	(0.0005)	(0.0113)	(0.0245)	(0.0007)	(0.0004)	(0.0006)	(0.0002)	(0.0021)
Observations	52893	8330	8330	8239	8209	4131	8289	8289	1618
Control group mean	0.1700	0.4400	35.2500	8.0000	0.3600	0.0500	0.2300	0.0200	9.6000
Donut FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Geographic sample	Full	In-migrant	In-migrant	In-migrant	In-migrant	In-migrant	In-migrant	In-migrant	In-migrant
Specification	XS	XS	XS	XS	XS	XS	XS	XS	XS
Hansen's J p-value	0.9779	0.8533	0.2909	0.7511	0.2635	0.9983	0.1614	0.0935	0.4959
First-stage F-stat	12.7752	15.9703	15.9703	16.3741	15.7886	15.2556	16.0612	16.0612	14.9671

Results shown for second stage of 2SLS estimate. Each observation is one adult. The dependent variable in Column 1 is an indicator for an in-migrant, i.e. a household or individual who moved in to his / her current residence after the Green Line was completed. Columns 2-9 show estimates on the subsample of in-migrants. Standard errors clustered at the zone level. * $p < .1$, ** $p < .05$, *** $p < .01$.

References

Angrist, J. D. and Krueger, A. B. (2001). Instrumental Variables and the Search for Identification: From Supply and Demand to Natural Experiments. *Journal of Economic Perspectives*, **15** (4), 69–85.

Baum-Snow, N., Brandt, L., Henderson, J. V., Turner, M. A. and Zhang, Q. (2017). Roads, Railroads, and Decentralization of Chinese Cities. *The Review of Economics and Statistics*, **99** (3), 435–448.

— and Kahn, M. E. (2000). The effects of new public projects to expand urban rail transit. *Journal of Public Economics*.

— and — (2005). Effects of Urban Rail Transit Expansions: Evidence from Sixteen Cities, 1970-2000. *Brookings-Wharton Papers on Urban Affairs*, (2005), 147–206.

Billings, S. B. (2011). Estimating the value of a new transit option. *Regional Science and Urban Economics*, **41** (6), 525–536.

Cookson, G. and Pishue, B. (2017). INRIX Global Traffic Scorecard. *Inrix Global Traffic Scorecard*, (February), 44.

EMBARQ (2017). Global BRT Data.

Gibbons, S. and Machin, S. (2005). Valuing rail access using transport innovations. **57**, 148–169.

Glaeser, E. and Henderson, J. V. (2017). Urban economics for the developing World : An introduction. *Journal of Urban Economics*, **98**, 1–5.

Glaeser, E. L., Kahn, M. E. and Rappaport, J. (2008). Why do the poor live in cities? The role of public transportation. *Journal of Urban Economics*, **63** (1), 1–24.

Gonzalez-navarro, M. and Turner, M. A. (2014). Subways and Urban Growth : Evidence from Earth. **1**.

— and — (2016). Subways and Urban Growth: Evidence from Earth.

JICA (2012). Lahore Urban Transport Master Plan: Final Report.

Malik, A. A. (2015). Exploring the dynamics of urban development with agent-based modeling: The case of Pakistani cities. *George Mason University*, pp. 1 – 237.

Pojani, D. and Stead, D. (2015). Sustainable Urban Transport in the Developing World: Beyond Megacities. (2), 7784–7805.

Redding, J. and Turner, M. A. (2015). *Transportation Costs and the Spatial Organization of Economic Activity*, vol. 5. Elsevier B.V., 1st edn.

Timilsina, G. R. and Dulal, H. B. (2010). Urban Road Transportation Externalities: Costs and Choice of Policy Instruments. *World Bank Research Observer*, **26**, 162–191.

Tsivanidis, N. (2017). The Aggregate and Distributional Effects of Urban Transit Infrastructure: Evidence from Bogotá's TransMilenio.

US Department of Energy (2017). Transportation Energy Data Book. **36**.

Winston, C. and Maheshri, V. (2007). On the social desirability of urban rail transit systems. **62**, 362–382.

World Bank (2013). *Global Monitoring Report*.

Wright, L. and Hook, W. (eds.) (2007). *Bus Rapid Transit Planning Guide*. June.

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