Why Should Developing Country Cities Reduce their Speed Limits? Evidence from São Paulo, Brazil

Amanda Ang   Peter Christensen   Renato Vieira*

Working Paper Version: December 12, 2018

Abstract

Cities throughout the world are experimenting with more stringent speed limits in an effort to reduce road accidents. The effectiveness of these policies is of particular interest for developing world cities, where a disproportionate share of accident damages occur but also where extant congestion creates heightened concern about speed reduction. This paper empirically evaluates a set of policies that changed traffic speed limits and enhanced its enforcement in São Paulo, Brazil. We exploit the temporal and spatial heterogeneity of policy adoption to examine the effectiveness and impacts of enforcement using measurements of traffic accidents, traffic tickets issued by monitoring cameras, and a panel of repeat observations of real-time trip duration for a representative sample of travelers before and after the new regulations. Our results indicate that speed limit reductions reduced number of accidents by 28.9% on treated road segments while not affecting traffic volume. We find that camera-based enforcement augmented the effect of the speed limit reduction. We find that speed limit *increases* on major urban highways reduced trip times by 7.5% during off-peak periods, though we find no significant effects during peak hours. We estimate that the social benefits from the reduction in road accidents are at least 2.13 times larger than the costs of longer commutes. The benefits of accident reductions accrue largely to lower income pedestrians and motorcyclists, indicating that speed limit reductions have an important progressive welfare impact in developing country cities.

*Ang: Department of Economics, University of Southern California, 300 Kaprielian Hall, 3260 Vermont Avenue, Los Angeles, California 90089 (email: qang@usc.edu); Christensen: Department of Agricultural and Consumer Economics, University of Illinois, 431 Mumford Hall, 1301 W. Gregory, Urbana, Illinois 61801 (email: pchrist@illinois.edu); Vieira: Department of Agricultural and Consumer Economics, University of Illinois, 431 Mumford Hall, 1301 W. Gregory, Urbana, Illinois 61801 (email: renato.sv.1988@gmail.com). We are grateful for helpful comments from Andre Chagas, Sandy Dallerba, Marieke Kleemans, Gabriel Kreindler, Mary Arends-Kuenning, and Julian Reif. We thank participants at the Federal University of São Carlos Economics Seminar, the University of São Paulo Economics Seminar, the University of Illinois Pere Seminar, and the Urban Economics Association Annual Meeting (2018) for helpful comments. We thank computer scientists in the UIUC Big Data in Environmental Economics and Policy Research Team for excellent programming work. In particular, we acknowledge Stephen Sullivan, Elena Lee, Nate McCord, Surya Tadigadapa, and Abhishek Banerjee. This work was made possible by generous support from the Lemann Institute for Brazilian Studies and the National Center for Supercomputing Applications. All data and replication files will be made available in the following data repository: https://github.com/uiuc-bdeep/speed_change (DOI: 10.5281/zenodo.2000257). All errors are our own.

Key words: Speed Limit Changes, Road Accidents, Transportation, Congestion
JEL Classification: H23, Q58, R41

Road injuries are the leading cause of unnatural deaths worldwide, representing 27.1% of all human unnatural deaths (1.3 million fatalities per year) and approximately one third of the external costs related to private transportation (WHO, 2015, Parry and Small, 2005, Parry et al., 2007). In an effort to address this worldwide problem, the UN World Health Organization (WHO) has declared the present decade (2010-2020) the "Decade of Road Safety" and promulgated the ambitious goal of averting 5 million road fatalities during this period. The WHO cites rapid growth in motorization in the absence of concomitant improvement in road safety strategies (such as appropriate speed limits) as a key factor driving the growth in accident damages worldwide (WHO, 2015). Road safety is particularly problematic in the developing world. Although low- and middle-income countries account for only half of world's vehicles, 90% of road fatalities occur in those countries. Figure 1 illustrates differences in magnitude and composition of road fatalities in São Paulo relative to New York City, the largest cities in Brazil and USA. Between 2012 and 2016, road fatalities per resident were almost 3 times larger in São Paulo than in New York. The composition of road fatalities also differs, with a much larger share of motorcycle driver deaths in the Brazilian city. Road accidents in São Paulo represent a more important contributor to fatality risk than physical violence.

In an effort to mitigate road accidents and achieve the goals set by the WHO, cities throughout the world have been experimenting with more stringent speed limits and improving speed limit enforcement on urban roads.[1] The rationale behind the focus on speed limit regulations is the growing body of evidence of a strong correlation between vehicle speeds and the probability and severity of road accidents (Vadeby and Forsman, 2017, Musicant et al., 2016, Li and Graham, 2016, Sayed and Sacchi, 2016, Pauw et al., 2014, Elvik, 2013, Archer et al., 2008, OECD/ECMT, 2006, Woolley, 2005). However, reducing speed flows may pose an important welfare cost as commuters face longer journeys and the empirical literature is less clear on the magnitude and significance of these effects (Archer et al., 2008). While there is evidence that well-enforced speed limits tend to reduce vehicle speeds (Archer et al., 2008, Wilmot and Khanal, 1999, Musicant et al.,

[1] OECD/ITF (2018) presents a comprehensive review of speed limit policy changes in recent years.

2016), there is little direct evidence on accident outcomes in developing country cities where baseline accident rates are higher and enforcement may be limited. Therefore, the net benefit of increasing the stringency of speed regulations is still largely an open question, particularly in developing country cities where they would likely have the greatest impact on both accident reductions and increased drive times. Not surprisingly, some of the most highly congested cities in the world have been reluctant to propose or adopt reduced speed limits.

This paper brings together a number of novel data sources to provide the most comprehensive set of estimates to date on the effects of reduced speed limits in one of the most congested cities of the developing world. In 2015, the government of São Paulo, Brazil, enacted a policy program that successively reduced speed limits on the city's highways (Marginais) and arterial roads.[2] However, the policy became highly contentious and in early 2017, the speed limits on urban highways reverted to pre-reduction levels. We exploit both the treatment (speed limit reduction) and reversal (speed limit increase to pre-policy levels) to identify the impacts of the policy, using a combination of detailed data on the universe of traffic accidents, ticketing from on-road traffic cameras, and trip durations queried in real-time from Google's transit API as the policy was reversed.[3]

Our results indicate that the 2015 speed limit reductions reduced road accidents by at least 28.9% on treated road segments, resulting in approximately 1,858 averted road accidents and 97 averted fatalities within the first 18 months of adoption and R$ 966 million in monetized benefits[4] per year. São Paulo's system of camera-based speed enforcement may have been important factor in achieving reductions – we find that roads where speed limit reductions occur alongside contemporaneous onset of camera-based enforcement experienced an additional 9-10% reduction in accidents. We find fairly modest effects of the speed limit change on commute times.[5] Travel speeds on treated highways increased by

[2]Speed limits were reduced from 90 km/h to 70 km/h on highways and from 60 km/h to 50 km/h in arterial roads. Section 2 describes in further details these policy changes.
[3]API stands for application program interface.
[4]Unless expressed otherwise, all results are presented in year 2015 Brazilian Reais (R%). The 2015 exchange rate 1 USD = 3.2551 BRL
[5]In this paper, we use the terms commute times, travel times, drive times, and trip times to refer to the duration of private, motorized transportation throughout the city of São Paulo. Our results are representative of trips defined in the São Paulo origin-destination travel survey, which is described in

about 6% as a result of the 2017 speed limit increase and that effects were concentrated in off-peak hours. In order to interpret these results in terms of overall benefits and costs, we compare the social cost of increased trip duration from reduced speeds with the benefits of reduced accidents. Using standard parameters for the value of time, the value of statistical life, and non-fatal costs of accidents, we find that the benefits associated with reduced accident damages are 2.13-4.75 times larger than the costs of longer drive times.

This paper makes a final contribution by examining the extent to which speed limit reductions have progressive/regressive impacts, which is an important and unresolved issue in the transportation literature (van Benthem, 2015). We find that the costs associated with increased travel time (slower trips) accrue disproportionately to wealthier individuals that have higher rates of private vehicle ownership and commute on treated roads. This is expected. However, we find evidence of a striking difference in the distribution of the benefits from accident reductions across income groups. 86% of the benefits of reductions in accident damages in São Paulo accrue to low-income residents, who bear a disproportionate share of the accident risk as pedestrians and motorcyclists. Our analysis reveals that speed limit reductions have strongly progressive impacts in cities such as São Paulo and may have important effects on reducing unnatural deaths in low-income populations in urbanizing regions of the developing world. For instance, the speed limit reduction appears to have had a considerably larger impact on reducing fatalities than gun control policies aimed at reducing violent crimes in São Paulo, which are responsible for a similar number of annual fatalities in the city.[6]

This study builds on other recent work that uses real-time web routing services to study the impact of urban transportation policies and congestion in developing country cities (Hanna et al., 2017, Akbar et al., 2018, Akbar and Duranton, 2017).[7] With respect to the analysis of policy impacts on travel time, our study is novel in combining a city-

Table A.3. They are not particular to work trips.

[6]Recent papers have identified an 11-13% reduction in fatalities as a result of a disarmament and conceal carry policies on fatalities in Brazilian cities over the past 15 years (Schneider, 2018, Cabral, 2016, dos Santos and Kassouf, 2013). See Figure 1 for a comparison of unnatural death rates attributed to road accidents versus violent crime in São Paulo.

[7]Hanna et al. (2017) evaluates the reduced-form effects of a policy change and is more similar to this study. Akbar and Duranton (2017) and Akbar et al. (2018) study congestion and mobility using structural methods.

wide sample of representative trips from an origin-destination travel survey with a web routing service that collects real-time congestion information. By simulating this set of representative trips before and after the speed limit change, we are able to attribute the policy impacts to individuals who vary in the types of trips that they are taking, in their value of time, and in their accident risk. Our results indicate that this is an important methodological choice that can have first-order impacts on estimates of commute costs. In our setting, we find that failing to account for (otherwise unobservable) heterogeneity in the population of travelers who utilize treated roads would attenuate our cost estimates by approximately 50%. This pairing of a travel survey with real-time congestion data also allows for analysis of distributional impacts of transportation policies.

This paper also builds upon prior studies that have evaluated the positive and negative economic impacts of speed limit changes. Two notable examples are van Benthem (2015) and Ashenfelter and Greenstone (2004), which study speed limit increases on American highways in the 1980's and 1990's. Our paper extends this literature in a number of ways. We estimate the impacts of speed limit changes on the key transportation corridors of one of the most congested cities in the world. It is not clear that the available findings from highways in the United States will generalize to the developing-country setting. Our findings indicate that speed limit reductions are, in fact, benefit-enhancing in São Paulo and provide evidence on enforcement and distributional concerns that may be common to many developing country cities. We are aware of at least one other attempt to evaluate the effects of São Paulo's 2015 speed limit reductions that focuses on effects on accidents (Jardim, 2017).[8]

The remainder of the paper is structured as follows: Section 1 describes the speed limit changes investigated in our study, Section 2 details the data sets used for our analysis, and Section 3 presents our main empirical strategies and reduced-form estimates. In Section 4, we compare the costs and benefits of the policies, including our distributional analysis. Section 5 concludes.

[8]In an unpublished master's thesis, Jardim (2017) evaluates accident reductions during the 2015 reduction using observations of accidents at road intersections throughout the city.

1 Background

With more than 20 million residents, São Paulo is one of the largest metropolitan areas in the world. The city is characterized by high urban density, limited transportation infrastructure, and a high spatial concentration of the country's economic activity (Rode et al., 2009). These factors have produced one of the most heavily congested urban areas in the world. Approximately 30 million motorized trips are made on an average weekday in São Paulo, out of which approximately half are made by public transportation and the other half by private modes (METRO, 2013). The distance of the average motorized trip in São Paulo is 8 km, though the mean trip duration is 51 minutes.[9]

1.1 Speed Limit Reductions in 2015

Travel-related injuries are a major problem in São Paulo. During the 2005-2014 period, there were on average 12.5 deaths per 100,000 residents in the Metropolitan Area of São Paulo (DATASUS, 2018), a ratio that is 56.2% higher than the OECD average. With growing awareness of the magnitude of the problem, the government of São Paulo joined the World Health Organization's "Decade of Action for Road Safety" by setting a target for reducing road mortality in the city to 6 deaths per 100,000 inhabitants by 2020 (CET, 2016). In 2015, the city implemented a program of speed limit reductions on major urban roads throughout the city. The program had two major phases: (1) On July 20, 2015, the speed limit of the main urban highways of the city (Marginais)[10] was reduced from 90 km/h to 70 km/h.[11] (2) Over the following six months, speed limits on city arterial roads were successively reduced from 60 km/h to 50 km/h[12] (CET, 2016). By the end of

[9]Table A.3 in Appendix A presents further details about the characteristics of motorized trips made in São Paulo on a regular weekday.

[10]The name "Marginais" comes from the location of these highways, which run along the banks (*margens* in Portuguese) of the Pinheiros and Tietê rivers.

[11]These values correspond to the speed limit reduction on the express lanes of the Marginais Highway. On the intermediary and local lanes of the highways, speed limits were reduced respectively from 70 km/h to 60 km/h and from 70 km/h to 50 km/h.

[12]The only exceptions were the "Corredor Norte-Sul" (North-South Corridor), where the speed limit was reduced from 70 km/h to 60 km/h, and a small number of arterial road segments where the speed limit was reduced to 40 km/h.

this process, the speed limits on approximately 570 km of roadways had been changed.[13] These road segments constitute 4% of the road network and 29% of private vehicle VMT in São Paulo.[14]

Another major component of the road safety program involved the concomitant expansion of speed control cameras, which is the dominant method of speed limit enforcement in Brazil.[15] Automated traffic cameras register vehicle speeds and issue speeding tickets to vehicles that are traveling above the speed limit (CET, 2016).[16] Figure 2 plots the growth in the number of speed control cameras installed in São Paulo between 2014 and 2016. The total number of cameras increased from 397 in the beginning of 2015 to 733 by the end of that year, an increase of about 83%.

A large fraction of the new cameras were installed on arterial roads and highways where speed limits were reduced.[17] While 55.6% of the cameras installed before July 20, 2015 were located on road segments that would undergo speed limit reductions by the new program, that share increased to 69.1% as additional cameras were installed. The design of the program resulted in four different policy conditions during the study period: (1) road segments where no change occurred, (2) road segments with new camera-based enforcement and no speed limit reduction, (3) road segments with speed limit reduction and no new camera-based enforcement, and (4) road segments with speed limit reduction and camera-based enforcement.

[13]Figure A.2 in Appendix A maps the roads where speed limits were reduced, indicating the final speed limit in each treated road segment after the 2015 changes. Figure A.3, also in the same appendix, plots the cumulative length of roads which were treated during the study period. The total length of treated segments increased at a near constant rate, suggesting that the implementation of speed limit reductions was relatively evenly distributed throughout the second half of 2015. This estimate of treated road length does not weight treated segments by the corresponding number of lanes.

[14]These figures were calculated by the authors by analyzing the simulated paths of trips reported in the 2012 Mobility Survey and the city's road network. VMT = Vehicle Miles Traveled.

[15]Human policing accounts for fewer than 8% of the 2-3 million tickets issued for failure to comply with the São Paulo driving restriction and none of the 5-6 million speeding tickets issued per year in the City.

[16]The fees for speed limit violations are defined by the National Traffic Code (Código de Trânsito Brasileiro). In 2015, the penalties for speeding were: a) R$85.13 for speeding up to 20% above the speed limit, b) R$127.69 if 20%-50% above the limit, c) R$574.63 if speeding above 50% the limit. In November 2016, these amounts were updated to respectively R$130.16, R$195.23 and R$884.41

[17]Figure A.5 in Appendix A compares the location of cameras installed before and after the first speed limit reduction implemented on July 20, 2015, and Figure A.6 maps the location of the new cameras installed after that same date.

1.2 Marginais Highways: Speed Limit Reversal in 2017

In January 2017, the speed limit on the Marginais Highways was returned to pre-2015 levels (raised back from 70 km/h to 90 km/h). This measure was a major campaign promise of the winning mayoral candidate during the election of 2016 and was adopted within the first month of his becoming elected. The debate about urban speed limits was a contentious topic during the political campaign.[18] Contrary to the speed limit reduction of 2015, the reversal was restricted to the Marginais Highways and the speed limits of the arterial roads remained unchanged from their post-2015 levels. Compensating safety measures were also adopted to attenuate a possible hike in accident risk.[19]

2 Data

This section describes the datasets that we combine to evaluate the impacts of speed limit changes on accidents, commuting time, traffic volume and traffic tickets.[20]

2.1 Road Segments with Speed Limit Changes

During the period when speed limit reductions were implemented in 2015, the traffic agency of São Paulo (CET) posted a series of announcements on its website to provide details about each upcoming speed limit change. These announcements described the exact road segments which would have their speed limit reduced and the date on which the change would be implemented. These announcements also described the existing speed limit of these segments and the new limits that would be adopted.

We collect all such reports from the agency website and, using their exact geocoded location and date, identify the roads and timing of speed limit changes. In total, the 37 reports used in our study describe the speed limit changes implemented on 202 differ-

[18]Examples of the debate during the electoral campaign can be found at goo.gl/Ju38zV, goo.gl/LRFWsA and goo.gl/bXW82N.

[19]These measures included: the construction of elevated road steps on pedestrian crossing points at Marginais feeder lanes, placement of signs warning drivers about the presence of pedestrians, placement of traffic agents with speed control pistols along the Marginais Highway, and the restriction of motorcycles during certain periods of the day (CET, 2016).

[20]Figure A.8 in Appendix A summarizes these datasets and their temporal coverage.

ent roads in São Paulo, including approximately 570 km of treated roads.[21] We divide treated and non-treated roads into segments of 400 meters in order to capture the effects of camera-based enforcement and other heterogeneous conditions along roadways. The resulting panel consists of a segment-specific count of accidents per month. Before the new speed limit was enforced on each segment, the traffic agency of São Paulo placed a series of traffic signs and banners on those segments indicating the upcoming speed limit change.[22] These warnings may have caused anticipatory effects in the weeks leading up to a change. We test for any bias arising from potential anticipation in our main empirical specifications by excluding observations of segments from the quarter immediately before the speed limit change on each road.

2.2 Traffic Accidents

We construct a panel dataset of accidents by road segment-month using data from the São Paulo Traffic Agency's yearly reports of road accidents from 2012 to 2017. These reports contain information for all road accidents registered within the city of São Paulo by the police departments, traffic agents, hospitals, and morgues (CET, 2017).[23] For each accident, we observe: exact location, time, number of victims, vehicles involved, the severity of injuries for each victim (unharmed, injured, dead), the alcohol level of drivers, victim's age, gender and educational attainment, and the types of vehicles involved in the accident (car, van, motorcycle, etc.). Table 1 reports descriptive statistics of the accidents included in our dataset. Between 2012 and 2017, 125,769 accidents were recorded in São Paulo, involving 146,991 injured victims and 5,997 fatalities. 5,016 (3.10%) of these accidents and 276 (4.6%) of the fatalities took place on the Marginais Highways, the main urban highways of São Paulo and the set of roads which were affected by both the speed limit reductions of 2015 and reversal in 2017. The number of accidents per year declined throughout São Paulo during this period, a secular trend that is observed

[21] Appendix A describes the 37 announcements used in our study.

[22] Appendix B shows an example of such banners and signs.

[23] We requested access to the individual accidents data from these reports using the Brazilian Law of Access to Information (Lei de Acesso à Informação). The requests for our project were registered as LAI request 21,151 and opened on March 31, 2017. LAI request 25,968 opened on November 1, 2017, and LAI request 30,818 opened on May 23, 2018.

even before the implementation of speed limit reductions. A variety of factors have been proposed to explain the overall downward trend, including improved safety features in vehicles and other public policies such as stricter laws to punish drinking and driving (Campos et al., 2013).[24]

2.3 Travelers and Trips in São Paulo

In order to measure the effects of the speed limit changes on the duration of trip times, we simulate a set of representative motorized journeys using the Google Directions API, which identifies an optimal route for pairs of origin and destination coordinates. The API estimates the travel time for simulated trips given real-time traffic conditions that are collected from drivers using Google Maps routing services and GPS information from mobile phones (Google, 2009). Travel time and vehicle speed databases with high temporal and spatial granularity are not readily available for São Paulo, increasing the value of data from Google and other similar providers.

We note two additional advantages of the Google Directions API relative to more conventional observations of traffic counts and vehicle speeds on highways in policy evaluation. First, the outcome measure that we are generally interested in when studying transport demand is a change in the duration of a potential trip for a given set of travelers (given their value of time). The conversion of traffic counts and flows into trip duration requires restrictive structural and functional form assumptions regarding optimal routing behavior. Second, it is often difficult to represent the change in optimal route immediately following a policy shift, which is extremely important in an event study of this kind given that drivers are assumed to be optimizing in real time. The Google Directions API provides the outcome measure directly and adjusts in real-time based on evolving traffic conditions. The assumption made here is that travelers will use the most efficient paths from origin to destination, as represented by Google's routing algorithm. To the extent that a policy change makes new routes more efficient, these gains will be captured in

[24] Stringent drinking and driving legislation was implemented in 2008 (*"Lei Seca"*). It was updated in 2012 with more stringent rules and in Nov. 2016 with higher fees. Cities and states are regularly running campaigns and programs to advertise and enforce these laws.

estimated effects.

Our sample of origin-destination pairs is taken from the São Paulo 2012 Mobility Study, a household travel survey that was designed to be representative of commuting patterns in the whole Metropolitan Region of São Paulo on a regular weekday. The survey collected detailed information about 46,861 trips taken by 8,115 households. Using the exact origin and destination coordinates (latitude/longitude) for private motorized trips reported in the survey, we queried the Google Directions API at 20-minute intervals to construct a panel of trip-specific travel times given real-time traffic conditions.[25] Table 2 presents descriptive characteristics of the simulated trips from our study. In total, we simulated 1.47 million trips between July 2016 and September 2017.[26] Out of this total, 243.7 thousand trips had at least 400m running through the Marginais Highways. We define this subset of trips that used the Marginais Highways as the treated units in the natural experiment.[27] The table compares the mean characteristics of all queried trips with the ones within that subset. In both cases, about a third of all simulations were crawled after the speed limit reversal, and about 40% of the queries were made during peak hours. The overall average estimated travel time was 20 minutes, with an average length of 8.31 km. In the case of trips using the Marginais Highways, the average trip length was 122% longer (18.5 km), although the average trip duration was only 92% longer (38.4 minutes). Therefore, although trips using the Marginais Highways were considerably longer in length, they tended to have a higher average speed. The mean trip that uses the Marginais Highways spends about 22% of total trip time on the Highways.

[25]In our main policy analysis, we calculate the social costs of speed limit reductions based on changes in the estimated travel time of individuals who travel by private modes. Very few bus routes circulate on the Marginais highways and only 1.7% of public transit trips take place on bus routes that run in the Marginais highways.

[26]Except for the period between March 15, 2017 to May 21, 2017 when the crawler was inactive.

[27]In our empirical model, the percentage of each trip that is taken on the Marginais Highways defines the intensity of treatment for each observation. For example, a trip that is 50% made on the Marginais Highways has a treatment intensity of 0.5.

2.4 Electronic Traffic Tickets and Cameras

Our study also examines traffic tickets issued by traffic monitoring cameras in São Paulo.[28] The cameras automatically identify traffic violations and tickets are mailed to the driver's residence. Speeding tickets received by mail are the main form of speed limit enforcement in the city. Each observation in the tickets dataset contains information about: (1) the type of traffic violation that was registered, (2) the date and hour of its occurrence, and (3) its location. Table 3 summarizes the sample of traffic tickets, which includes all tickets issued by cameras in São Paulo between 2014 and 2017.[29] In total, more than 35 million traffic tickets were issued during that period, with an average of 9.46 million tickets per year. In 2015, the total number of tickets increased by more than 53%, and then by 26% in 2016. However, in 2017, that number decreased by almost 16%. Across the entire study period, speeding tickets make up approximately half of all traffic violations. Approximately one quarter of all traffic tickets were issued by cameras located on the Marginais Highways.

We use observed traffic violations and camera locations in three different ways. First, we identify the presence of speed monitoring cameras on all segments included in our analysis, identifying precisely when cameras are installed or discontinued. We use this variable to estimate the interaction between the effect of speed limit reductions and the effect of contemporaneous introduction of camera-based enforcement through the installation of a new camera on the same segment. Second, we evaluate spillovers in the effect of speed limit reductions on the number of speeding tickets on non-treated segments. If São Paulo drivers began to drive more carefully in general after the policy, then we would expect to observe a reduction in speeding tickets on segments that are not treated. This type of spillover could lead to downward bias in estimates of policy effects, so this serves as an important check on our exclusion restriction. Finally, we use the volumes of tickets that are *unrelated* to speeding to construct a proxy for driver

[28] This data is available at the website "Painel Mobilidade Segura" (http://mobilidadesegura.prefeitura.sp.gov.br), maintained by the São Paulo traffic agency.

[29] Traffic tickets can be issued manually by the police and by traffic agents. In the case of speeding violations, tickets are only issued by the automated cameras (there are no observed tickets issued by police in our data). In the case of driving restriction violations, manual policing accounts for about 7% of all tickets.

volumes per segment over time. To do this, we first count driving restriction tickets per segment.[30] Next, we do the same for all other types of tickets, such as red light violations, illegal turns, etc. In each case, we assume that the number of non-speeding violations per camera is a function of the number of cars circulating on monitored road segments and use this proxy to test for evidence of substitution away from treated roads after the speed limit reductions.

3 Empirical Model and Reduced Form Results

This section describes the empirical models used to estimate the impacts of speed limit changes in São Paulo. We begin by estimating the effect of the 2015 speed limit reductions on road accidents and then we examine the effect of the speed limit increase of 2017 on travel times.

3.1 Did São Paulo's Road Safety Policies Reduce Accidents?

We exploit temporal and geographical variation in speed limit reductions adopted in São Paulo as a natural experiment that allows us to identify the effects of speed limit changes on road accidents. Our empirical setting includes a repeat sample of accidents on road segments that were treated at different points in time (as well as on segments that were never treated). We estimate the effects of the speed limit reductions using a semi-dynamic event study design (Borusyak and Jaravel, 2016).[31] The primary assumption underlying identification is that changes in road accidents observed on a treated segment follow a path parallel to what would be observed on treated segments in the absence of the policy.

3.1.1 Semi-dynamic Event Study With Controls

In addition to this semi-dynamic event study specification, we estimate the model using 4 alternative samples of control segments. Sample (1) includes all treated segments and

[30] Appendix D describes the details of the Driving Restriction policy adopted in the City of São Paulo.
[31] Refer to Borusyak and Jaravel (2016) and Abraham and Sun (2018) for recent reviews of event study research designs.

introduces the most general sample of controls: all never-treated road segments in São Paulo. However, there are two potential concerns with this sample: (a) most trips use a combination of treated and non-treated roads and drivers may not be cognizant of the exact geographic delineation of the policy, so speed limit reductions could potentially affect driver speeds and accident risk on nearby roads and (b) the selection of treated segments is not random. To address potential bias from behavioral spillovers, in sample (2) we exclude all control segments located within 1.6 km of any treated road.[32]

Samples (3) and (4) address concerns regarding the non-random selection of never-treated segments by selecting control segments that are highly similar to the treated segments in accident risk. Sample (3) is a subset of treatment and control road segments on which more than 12 accidents occur during the pre-treatment period.[33] Sample (4) constructs a matched sample where each treated segment is matched with one control segment based on the total number of accidents on the pre-treatment period.

Sample (5) is the basic event study with heterogeneous treatment timing and does not include any never-treated segments as controls. Instead, we control for secular changes in driver behavior across the time series with a linear time trend and two covariates that capture aggregate changes in driving behavior during the period: (1) the log of fuel sales in the State of São Paulo and (2) the log of the total number of speed monitoring cameras in São Paulo.

Figure 3 maps the segments included in each of the samples described above. Each panel of the figure shows the treated and control groups used in samples (1)-(4).[34] By comparing Panel A to Panel B, we see that the 1.6 km restriction in Sample (2) excludes all control segments located in the central part of the city. Panel C illustrates that sample (3) imposes a considerable restriction on control and treatment segments. Panel D shows

[32]Appendix G describes these results of our analysis of behavioral spillovers. Using data from electronic speeding tickets on non-treated road segments, we find evidence that the number of speeding tickets per camera decreased on segments within 1.6 km of treated roads. This result suggests that drivers may have responded by driving more carefully not only on treated segments, but also on nearby roads. We also find evidence of a significant decrease in road accidents within the same 1.6 km zone, providing further evidence of spillover effects. However, we find no evidence of spillovers beyond 1.6 km of treated roads.

[33]This threshold corresponds to the mean number of total accidents per segment in the pre-treatment period in the subset used in sample (2).

[34]Sample (5) segments are the treated segments in Panel B.

that the matching strategy places greater restriction on the control group.

Figure 4 plots the time series of road accidents on the treatment and control groups used in samples (1)-(4). The average number of accidents per km for both groups is normalized using on the values observed in June of 2015, which is the last month before the first speed limit reduction in São Paulo. The patterns observed in the figure are similar across all control groups: both the treatment and control groups present a decreasing trend in accidents per km over the study period, with clear evidence of a larger reduction in accidents on treated segments that coincides with the onset of the speed limit change.

We use the following Event Study Poisson model of accident counts[35] to estimate of the impact of changing the speed limit:

$$log\left(E\left(y_{it}\right)\right) = \alpha_i + \beta_t + \left(\sum_{q=1}^{7} \gamma_q D_{it}^{q}\right) + \zeta C_{it} + \eta C_{it} SLR_{it} + \phi SLI_{it} \tag{1}$$

Where y_{it} is the number of accidents on segment i during month t. On the right-hand side of Equation 1, α_i is a segment fixed effect that captures the time-invariant component of accidents on each segment observed in our sample. The fixed effect β_t measures the average change in accidents observed in each calendar month t that are common to all segments irrespective of treatment status, thus controlling for secular trends.[36] The variable D_{it}^{q} is an indicator for the number of q quarters relative to i's initial treatment, such that $q = 1$ is the quarter of initial treatment. All observations from the seventh relative quarter and beyond are pooled together in $q = 7$, which is our longest-term in the model and best estimate of the long-run effect of the policy. The primary coefficients of interest are the γ_q terms, which measure changes in the number of accidents on a treated segment in each of the quarters following the treatment of segment i.[37] For instance, γ_1

[35] We report estimates from an equivalent linear specification in Appendix F. No significant differences were observed between the Poisson and OLS estimates. Estimates from the Poisson model are converted to relative incidence ratios. Standard errors are adjusted using a delta method approximation.

[36] Sample (5) does not include control segments and is estimated without time fixed effects. We control for secular trends using a linear time trend, fuel sales and the total number of traffic monitoring cameras in São Paulo.

[37] Effects are therefore measured in terms of the relative time-distance (in quarters) to treatment. We aggregate the effects in terms of relative quarters for two reasons 1) by using a larger time interval, coefficients are more precisely estimated. 2) Aggregation by quarter allows us to present time-varying effects occurring across 8 quarters rather than 24 months (= 24 coefficients).

indicates the average relative change in accidents on treated segments during the first three months after speed limit reduction.

Model 1 includes two terms that estimate heterogeneity in the effect of speed limit reductions for segments that use camera-based enforcement: C_{it} and $C_{it} \cdot SLR_{it}$. The first term (C_{it}) is an indicator for the presence of a speed monitoring camera on segment i during month t, such that ζ estimates the change in accidents on road segments where camera-based enforcement is initiated during the study period.[38] The interaction term $C_{it} \cdot SLR_{it}$ is an indicator for whether the speed limit reduction policy occurred on a segment that also received camera-based enforcement, such that the coefficient η measures the interaction between the speed limit reduction and the onset of camera-based speed enforcement. Finally, SLI_{it} controls for observations where speed limit reductions were reverted in 2017.

In our baseline specification, we exclude observations from the quarter immediately preceding the speed limit change to address the possibility of confounding effect of anticipatory behavior resulting from the placement of banners and signs announcing upcoming speed limit changes.[39] Following the approach defined by Borusyak and Jaravel (2016), we conduct independent tests for pre-trends in subsection 3.1.2 and then omit leads for the quarters preceding the speed limit reduction in our primary specifications.

3.1.2 Tests for Differences in Pre-treatment Accident Trends

If the parallel trends assumption is valid, then no significant differences should exist in the average rates of change between the two groups in the periods before the policy adoption. We test the parallel trends assumption in the pre-treatment period by extending our baseline specification with leads of treatment associated with relative-quarters before the

[38]Since C_{it} is estimated conditional on segment-fixed effects, ζ measures the accident reductions associated with the onset of camera-based enforcement in a given month t.

[39]Figure B.1 on Appendix B shows an example of one these signs. In Appendix F, we estimate our empirical model without excluding data from the quarter immediately before the policy adoption to test for the robustness of results. Results that include the final quarter preceding treatment are slightly attenuated in the 1st quarter after the policy adoption, though long-run estimates are not sensitive to this choice.

speed limit reduction in each segment:

$$log\left(E\left(y_{it}\right)\right) = \alpha_i + \beta_t + \left(\sum_{q=-8, q\neq -1}^{0} \xi_q D_{it}^q\right) + \left(\sum_{q=1}^{7} \gamma_q D_{it}^q\right) + \zeta C_{it} + \eta C_{it} SLR_{it} + \phi SLI_{it} \quad (2)$$

If the parallel trends assumption holds, then all coefficients ξ_q should be equal to zero.[40] Figure 5 plots the coefficients γ and α for the samples of segments used in Model 1. Results are consistent across specifications. Relative to treated segments, accidents on control segments appear to increase slightly in the period 2 years before the policy change and then exhibit a parallel trend for the year preceding treatment. None of the coefficients associated with periods preceding treatment are statistically different from zero, providing support for the parallel trends assumption. We also note that the coefficients associated with the quarter immediately preceding the speed limit reduction do suggest a small reduction in accidents, which we attribute to anticipatory behavior induced by the installation of banners and signs on treated segments on the weeks preceding the speed limit change in each road. Observations from that period are excluded from our preferred estimates of policy effects.

3.1.3 Estimates of the Effect of Speed Limit Reductions

Table 4 presents our main estimates of the effect of speed limit reductions. All results indicate a significant reduction in accidents on treated segments after the speed limit reductions and that effects of the reductions increase over time. In our specifications with controls (1)-(4), we estimate a 9.1-18.4% decrease in the number of road accidents in the first quarter following the policy. The effect grows to 18.6-38% over a period of 6 quarters. These reductions correspond to 1,858-2,589 accidents and 97-136 fatalities averted in the first 18 months of the new policy. The point estimates from the most general sample (1) are the smallest in magnitude. This is not surprising, given the fact that this subset includes control segments in the vicinity of treated roads where driver behavior

[40]Note that due to concern about anticipatory effects in the period immediately preceding the policy change on each segment, we include a coefficient that controls for changes during the anticipatory quarter and set the second quarter preceding the reduction to be the reference period.

could potentially be affected by the new speed limits. If there are indeed spillover effects, then the results from this model would be biased downward, which is consistent with the estimates from specification (1). The three specifications that contain a restricted set of control segments beyond 1.6 km (2), a minimum number of 12 accidents per month in the pre-period (3), or are matched to treated segments using pre-period accident counts (4) indicate a narrower range of 28.9-31.2% in the final quarter of the sample. Given that effects grow over time, we cautiously interpret this range as the best (and perhaps a conservative) indication of the effect of the policy over a longer time horizon.

Results from the base event study specification that omits never-treated segments suggest that the immediate effect of 18.4% grows to 38% within 1.5 years of the change in speed limit. We note that these estimates involve a more restrictive set of assumptions about the functional form of secular trends that are affecting transport demand across the study period. Despite some important differences, we take the fact that results are aligned in terms of the general magnitude and specific pattern as a reassuring sign that these models yield a credible result for the magnitude of policy effects.

The estimates of heterogeneity in treatment effects as a function of camera-based enforcement also indicate a consistent pattern across specifications, though they are identified using changes in camera-based enforcement and are modeled with substantially less precision than the main effects. These results suggest that the onset of camera-based enforcement on a given segment had a negligible effect on accident risk *before* the speed limit reduction, but that camera-based enforcement augmented the impact of the speed limit policy by 8.6-10.6 percentage points (in models with control segments).

3.1.4 Specific Policy Effects on the Marginais Highways

One additional question related to the effects of speed limit policies on accidents concerns the specific case of the Marginais Highways. There are two main reasons to investigate the specific effects in these roads: (1) In 2015, the speed limit reduction in the Marginais Highways was from 90 km/h to 70 km/h, meanwhile, in arterial roads the reduction was from 60 km/h to 50 km/h. (2) In January, 2017, the speed limit in the Marginais

Highways was reverted to pre-reduction levels. A similar reversal was not not implemented on arterial roads.

To identify policy effects that were specific to the Marginais Highways, we create two sets of post-intervention groups: (1) Arterial Roads and (2) Marginais Highways. For the first group, the coefficients are equivalent to the baseline model. For the Marginais Highways, we also include a set of terms that estimate the effect of the the speed limit reversal of 2017 (which was specific to the Marginais Highway). This extended model is described by Equation 3 below:

$$log\left(E\left(y_{it}\right)\right) = \alpha_i + \beta_t + \left(\sum_{q=1}^{6} \gamma_q A_i D_{it}^q\right) + \left(\sum_{q=1}^{6} \delta_q M_i D_{it}^q\right) + \left(\sum_{q=1}^{4} \eta_q M_i R_{it}^q\right) + \zeta C_{it} + \eta C_{it} SLR_{it} \tag{3}$$

Where A_i is an indicator for arterial roads and M_i is an indicator for segments on the Marginais Highways. Additionally, R_{it}^q is an indicator that identifies observations occurring q quarters after the speed limit reversal. Therefore, while coefficients γ_q capture the effect on arterial roads in each quarter after the speed limit reduction, δ_q represents the corresponding coefficients for the Marginais Highways and η_q estimates changes in accidents after the speed limit reversal.[41]

Table 6 reports the longer-term effects of each policy and type of road at the longest term measured in the sample ($\gamma_{q=6}$, $\delta_{q=6}$ and $\eta_{q=4}$). The point estimates indicate a larger effect of the speed limit reductions on accidents on the Marginais Highways than on arterial roads. The point estimates for the highways indicate a reduction of 34.7%-50.2% depending on the set of controls, compared to 19.7%-39.1% in the case of arterial roads. However, the point estimates associated with the Marginais Highways are less precisely estimated given the smaller sample of segments observed in this group.

Our estimates of the effect of the speed limit reversal indicate an <u>increase</u> of 12.2%-16.9% in accidents after the speed limit <u>increase</u>. However, fewer segments were affected

[41] $D_{it}^{q=6}$ takes the value of one for all observations from treated segments that are from 6 *or more* quarters after treatment. Because of that, the coefficients η_q can be interpreted as the relative change in accidents after the speed limit reversal relative to the longer-term effect of the speed limit reductions.

by this policy and our sample is limited to the first four quarters after the policy adoption, both of which affect the precision of our longer-term estimates. Based on these results, we cannot rule out an effect of the same magnitude observed within the first four quarters of the speed limit reduction or a null effect. The point estimates suggest an effect of smaller magnitude than the total reduction in accidents in the Marginais Highways after the speed limit reduction. However, the concomitant adoption of compensating safety measures during the reversal limits the interpretation of these estimates as capturing the effect of the speed limit policy alone. We interpret the opposite effect sign of the point estimates for the speed limit increase as consistent with the expected relationship between speed limit regulation on accident risk. Though highly imprecise, we find the smaller magnitudes suggestive that compensating safety measures implemented at the time of the reversal may have had some mitigating effect on increases in accident risk during the reversal.

3.2 Behavioral Adjustment: Route Substitution and Speeding

Our results indicate that a significant reduction in accidents occurred on roads where speed limits were reduced in São Paulo. Our primary hypothesis is that this reduction in accidents was caused by lower accident risk as drivers began driving more slowly. However, the speed limit reductions could also affect accidents by inducing route substitution. If drivers substituted away from treated roads that had become slower as a result of the speed limit reduction, then this substitution would result in fewer vehicles driving on treated roads and consequently, fewer accidents. We test for evidence of route substitution using data on traffic violations resulting from infractions unrelated to speeding.[42] These tickets serve as a proxy for traffic volume per segment.

We also find that the impacts of the speed limit reduction in São Paulo were dynamic: we observe a substantial immediate effect that increased gradually over time. It is not immediately clear what causes the change in the impact of the speed limit reduction over

[42]The São Paulo driving restriction accounts for 56.6% of non-speeding traffic tickets. The remaining tickets include: driving in bus lanes (11.6%), cargo vehicles in restricted areas (3.9%), illegal right-turns (3%), red light violations (2.2%), driving in restricted lanes (4.1%), stopping in a pedestrian crossing area (0.8%)

time. An intuitive hypothesis is that there was a period of adjustment to the new regime after policy adoption. That is, following the speed limit reductions, some drivers may not immediately comply with the policy. Given strict camera-based enforcement, changes in driver behavior may involve a behavioral response to infractions and penalties. To test this hypothesis, we compare changes in speeding tickets issued on treated segments to tickets on segments that were not treated.

We test the effect of the speed limit reduction on traffic volumes (using tickets unrelated to speeding) and speeding tickets using a dynamic event-study model that mirrors our main empirical specification:

$$Z_{it} = \alpha_i + \beta_t + \sum \delta_{it} + \varepsilon_{it} \tag{4}$$

The dependent variable (Z_{it}) in this model is the log of tickets (speeding, driving restriction, or other non-speeding tickets) issued on segment i during month t. The model is estimated using the subset of road segments that possess a monitoring camera during the entire study period. In the case of non-speeding tickets, this model tests the hypothesis that the speed limit reduction caused lower traffic volumes on treated segments. Negative and statistically significant coefficients for δ_{it} provide evidence of reductions. In the case of speeding tickets, the dynamic coefficients serve as an indicator for driver's behavior adaptation. Postive and statistically significant coefficients for δ_{it} provide evidence of a lag in compliance.

Table 5 presents the coefficients δ_{it} from Model 4 for (1) speeding tickets, (2) non-speeding tickets. Non-speeding tickets are divided into driving restriction tickets and other types of tickets as a check for consistency across infraction type. The results illustrate a sharp and immediate **increase** (+85%) in speeding tickets on treated segments following the policy adoption, which we interpret as consistent with a model of drivers who lag in adjusting to the new regulatory regime. After the first two quarters, the number of tickets then begins to decrease, although it remains well above pre-treatment levels throughout the study period (+82%). This suggests a persistent set of non-compliers and the potential for larger accident reductions (effects) assuming that the rate of compliance increases and continues to reduce accident risk over a longer horizon.

The results for non-speeding tickets are quite different. They suggest that there may have been a slight (non-significant) decline immediately following the reduction, perhaps as drivers tested routing alternatives or increased their attentiveness, though ticket volumes revert to pre-policy levels after the first quarter of the new regime. Assuming that the volume of non-speeding tickets serves as a proxy for the volume of traffic on treated segments, these findings suggest no substantial or persistent patterns of substitution in routing or trip-taking. Estimates of accident reductions on nearby non-treated roads also reveal patterns contrary to evidence of route substitution.[43]

3.3 Did São Paulo's Road Safety Policies Affect Travel Times?

This section presents reduced-form estimates of the effect of the January 2017 speed limit increase on the travel time of drivers in São Paulo. Using the dataset of trips simulated on Google Directions API, we compare the estimated duration of trips that utilize the Marginais Highways to those that do not, before and after the policy change. Figure 6 illustrates our empirical strategy by comparing the average estimated travel time of crawled trips by week and by use of the Marginais Highways. The figure illustrates that treatment and control trips follow similar paths before the reversal. However, after the speed limit reversal the estimated travel time for trips that use the Marginais Highway tends to fall below the corresponding estimated travel time of other trips. Our baseline empirical strategy to formally estimate this effect is given by the following equation:

$$ETT_{ihd} = \alpha_{ih} + \beta Marg_i I_d + \gamma I_d + \delta X_{hd} + \sum_L \phi_L B_{Li} I_d + \varepsilon_{ihd} \tag{5}$$

where ETT_{ihd} is the log of estimated travel time for each simulated trip i queried at hour h on date d. α_{ih} is a trip-hour fixed effect that controls for trips specific characteristics such as length, path and departure time.[44] $Marg_i$ measures the fraction of each trip

[43]An analysis of changes in accidents on nearby road segments is presented in Appendix G.

[44]In this model, a trip is defined as a pair of origin and destination coordinates queried at a certain time of the day. Therefore, a query that simulates traveling from point A to point B at 7 am is considered as a distinct variant of the "trip" from the exact same query made at 8 am.

that takes place on the Marginais Highways and can be interpreted as a measure of the intensity of treatment for each trip. I_d indicates if the query was made after the speed limit increase in January 25, 2017. The coefficient γ captures the average change on estimated travel time for all trips and the coefficient β measures the additional travel time change that was specific to the proportional use of the Marginais Highways in the sample. X_{hd} is a vector of other controls, including the occurrence of rain in the moment of the query and if date d was a holiday in São Paulo.

It is likely that the effects of the speed limit increase will spill over beyond the Marginais Highways as drivers on adjacent roads adjust to new driving speeds and may be affected by changes in congestion near the treated zone. To account for these possible effects, we include in our specification a set of terms that identify the fraction of trips that take place within buffers of certain distances L from the Marginais Highways. In our baseline specification, we include three levels of non-overlapping buffers with respective distances of 1km, 3km and 5km. Figure A.7 in Appendix A illustrates these areas as well as zones delineated as controls that are less likely to be affected.

Table 7 reports the results from the regression model specified by Equation 5. The first column corresponds to the simplest version of our empirical model, where we do not include the spillover controls. In this case, the main estimates indicate a reduction of 6.5% in the travel time for a trip made entirely on the Marginais Highways. This effect accounts for an overall reduction of 1.8% in travel time for all trips in our sample irrespective of the Marginais effect. These estimates indicate that rain led to an average increase of 1.9% in travel time and trips on holidays were on average 10% faster.

In Column 2, we include covariates that measure the portion of a trip that takes place in spillover zones that may have been indirectly affected by the speed limit change in the Marginais Highways. The inclusion of these variables reduces the main treatment effect to 5.8% for a 20 km increase in the speed limit. However, for the portion of trips taking place within 1 km of the Marginais, the results indicate an average estimated reduction of 3.4% of a trip's duration, or approximately 60% of the main effect observed on the Marginais. Similarly, the estimated spillover effects on the 3 km and 5 km buffers were of respectively 27% and 15% of the main effect, although the latter was not statistically significant. In column 3, we include month-specific fixed effects, though they do not meaningfully affect any of these estimates. Taken together, these results suggest that the speed limit change did affect trip times on the Marginais Highways and also indirectly on nearby roads. Our estimates of main effects are robust to the impacts of spillovers.

Finally, Column 4 reports estimates from a specification that separates the main treatment effect into effects on trips taken during peak hours (7-10 am and 5-8 pm) versus effects on trips made during off-peak hours. These results indicate that the speed limit reversal disproportionately affects trips occurring during off-peak hours – the corresponding point estimate indicates an average reduction of 7.5%. The average reduction for trips taken during the peak period was of only 2.7% and the point estimate for this coefficient is not statistically significant. We interpret this difference as evidence that changes in speed limits likely have larger effects on free-flow traffic, when speed limits are more likely to act as a binding constraint. This heterogeneity has important implications for evaluating the cost of speed limit reductions in the context of congestion.

Finally, we estimate a dynamic event-study specification of our model where we interact our main treatment effect component with each quarter after the policy change (closely resembling the dynamic model used for accidents). Figure 7 presents these estimates, which indicate that the treatment effect of the policy seems to have increased over time. Spillover effects do not seem to present any clear dynamic pattern over time.

4 Cost-Benefit Analysis

In this section, we extend our reduced-form estimates to analyze the social costs and benefits of the speed limit changes that were implemented in São Paulo. We estimate the monetary value of road accidents and travel time using standard parameters from the literature, though we stress the limitations of the procedure given substantial uncertainty underlying both of these parameters. We construct counterfactual scenarios that allow us to compare a reasonable range of monetized benefits from reduced accidents to a reasonable range of costs from increased commute time in the context of the 2015 speed limit change in São Paulo. We focus our analysis on the Marginais Highways, where we are able to more directly compare accident gains from the speed limit reduction with travel time gains from the speed limit reversal.

4.1 Social Benefits of the 2015 Speed Limit Reductions

Our empirical estimates identify a significant and consistent effect of the speed limit reduction on accidents in São Paulo. In this section, we use the longer-term results from sample 4 in the extended model where we separate the impacts by road-type (Equation 3) as preferred estimates of the policy effect. This sample excludes control segments where driver behavior may have been affected by speed limit reductions on nearby roads and uses pre-treatment matches treated an control segments based on accident counts in the pre-treatment period. For comparison, we also present the results based on the reduced form results from sample 5, which completely excludes control segments.

We utilize the information specific to each accident to calculate the monetary cost of accidents using two sets of parameters. For costs to vehicles and to non-fatal victims, we use the associated estimates reported by IPEA (2016). This study from the Brazilian Institute of Economic Research estimates the average cost of road accidents in Brazil by accident severity and status of victims.[45] In the case of road fatalities, we use the Value of Statistical Life (VSL) of U$ 1.695 Million[46] estimated for Brazil by Viscusi and Masterman (2017).

In both cases, we use the final quarter of data (1.5 years post-implementation) as our best within-sample approximation of the longer-run effects. Based on these point estimates,[47] we construct two policy scenarios with alternative assumptions. First, we compute the expected number of accidents in the baseline period if speed limits were reduced but everything else remained constant. Next, we evaluate the case where speed limit reductions were accompanied by an increase in the number of cameras equivalent

[45] Appendix C presents all the parameters from IPEA (2016) used in our study.
[46] In 2015 USD.
[47] These estimates are the speed limit reduction results shown in Table 6.

to the expansion observed between 2015-2017. To compare the results with travel time gains, we restrict our analysis to accidents observed on business days[48] during the baseline period.

Table 8 reports the results of this analysis. First, the table reports the total number of accidents on treated roads that were observed in the baseline period (one year immediately before policy adoption) and the total monetary cost associated with these accidents. The following section of the table shows the estimated number of accidents and its corresponding monetary costs from the alternative policy scenarios constructed from reduced form estimates from samples (4) and (5). The total policy benefits of speed limit reductions without an increase in enforcement are estimated to be R$ 950 million using sample (4) versus R$ 1,236 million using sample (5). The Marginais Highways accounted for 17.6%-18.7% of total policy benefits. The scenarios simulating the offset of additional cameras indicate an additional total policy benefit of R$ 56.3 million in the case of coefficients from sample (4) and R$57.6 million for sample (5), corresponding to increases of 4.6%-5.9% in total policy benefits.

4.2 Benefits from the 2017 Speed Limit Increase

We calculate the social monetary value of time savings associated with the 2017 increased speed limits using two alternative parameters for the value of time (VOT). A first estimate is based on the after-tax hourly wages of individuals observed in the travel survey, which is similar to the method used in van Benthem (2015). Although we use this parameter for direct comparability between our results and Van Benthem's estimates from the United States, we interpret this value as a conservative upper bound for the benefits of the speed limit increase on travel time. The empirical literature has consistently identified an average VOT of approximately 50% of the wage rate (Wolff, 2014).[49] As an alternative parameter that is intended to capture heterogeneity in VOT across different types of trips, we calculate policy benefits using the Victoria Transport Policy Institute (VTPI)

[48] The household travel survey used to compute travel times is only representative of trips on business days, so we impose same restriction on the accidents data.

[49] The USDOT recommends assigning half of the hourly wage for non-business trips within local urban settings (USDOT, USDOT).

guidelines, which suggest assigning a VOT of 150% of travelers' wage for business trips, 50% for commuting (35% if passenger), 25% for personal travel, and 0% for leisure or vacation (VTPI, 2016). The survey records the self-reported income for all travelers and and motivation for all trips in our origin-destination sample. We use this information to calculate the VOT for each trip following the VTPI method. As has been documented throughout the transportation literature, we note that our post-estimation results are highly sensitive to this choice of VOT. In all results that follow, we therefore present two variants of each estimate to illustrate the range of estimates of policy cost given these two different definitions.

Table 9 reports the results of our calculations based on these two different parameters. The first set of columns refer to the results using after-tax hourly wage VOT and the second set reports the results using the VTPI VOT. As with the estimates of accidents, the first line of the table reports the baseline total cost of time in traffic observed in 2016, thereby accounting for the fact that the speed limit in the Marginais was 70 km/h in that year. Next, we calculate two distinct counterfactuals for the speed limit increase to 90 km/h, first including spillover effects on nearby roads and second restricting the travel time effects to treated roads only. In the first case, the value of total travel time savings is estimated to be R$ 134.8 million if we use our upper bound VOT and R$ 57.4 million if adopt the VTPI VOT. However, if we exclude the spillover effects, those values decrease to respectively R$ 56.8 million and R$ 25.5 million.

Compared to the existing literature that estimates the welfare impacts of speed limit changes, our study has the distinct advantage of basing our calculations on a representative sample of individuals. Because of that, we can identify the characteristics of individuals that were likely to be affected by the policy and estimate their corresponding welfare benefits according to individual-specific parameters. While this approach requires the assumption that the 2012 travel survey is representative of the types of individuals and trips that were taken in 2016/2017, it allows us to examine the distributional effects of the policy as well as accounting for heterogeneity in effects. In particular, it avoids possible bias associated with unobserved heterogeneity in the travel demand observed for individuals at different income/wage levels.

To illustrate the importance of accounting for this heterogenity, Table 10 compares our central estimates of travel time benefits with the estimates that come from a model that assumes the median VOT for all individuals in our sample. The comparison indicates that by assigning an individual-specific VOT, the total estimated benefits from the speed limit increase are about 50% larger. This difference is attributable to the fact that individuals who drive on treated roads tend to be wealthier than the median São Paulo resident. The correlation between income and transport behavior among São Paulo residents introduces substantial heterogeneity in effects and presents a first-order issue in benefit-cost analysis. It is worth noting that about half of households do not own a private vehicle in São Paulo, and are therefore unable to extract much, if any, direct benefit from a speed limit increase.

4.3 Comparing the Cost and Benefits of Speed Limit Changes

We compare the benefits of reduced accidents from the speed limit reductions of 2015 to the reduced costs associated with travel time savings from the policy reversal in 2017, which are different events. Any comparison of these two different events requires adjustments for comparability as well as the assumption that the travel time effects observed from the speed limit increase of 2017 are symmetric but inverse to the impact that would have been observed during the prior speed limit reduction on the same roads. This is not a testable assumption in our setting due to concomitant safety measures introduced with the 2017 reversal, although other studies have compared the effects of speed limit increases and reductions on travel time. In particular, a meta-study that analyzes the results of 108 events (speed limit changes) that examine driving speeds before and after speed limit increases/reductions in 20 different countries finds that the effects of increases in speed limits are not statistically different from the effects of speed limit reductions (Musicant et al., 2016).[50] The point estimates from this comparison suggest that, if anything, in-

[50]Estimates in (Musicant et al., 2016) are drawn from 28 studies in developed countries. Reported estimates are .0237 (0.09) for the pre/post effect of a 10% increase in the speed limit versus .0133 (0.139) for the pre/post effect of a 10% reduction in a speed limit. It is worth noting that our estimated effect of the São Paulo speed limit increase as measured by the Google API .057 (0.013) is in line with the estimates suggested by the meta-analysis. The speed limit increase in our setting was of 22.2% (90 km/h to 70 km/h), so the extrapolated effect for a 10% increase would be of approximately .0256 (0.005).

creasing speed limits may have slightly stronger effects than speed limit reductions by the same amount. This evidence suggests that our comparison will likely yield reasonable, if conservative, estimates of net benefits from the speed reduction policy.

There are two other important factors that differ between the speed limit reduction and subsequent increase. First, the former affected the city highways and arterial roads and included a large expansion of camera enforcement. Meanwhile, the speed limit reversal of 2017 was restricted to the Marginais Highways and was not accompanied by any substantial changes in enforcement. Therefore, to refine our comparison of policy costs and benefits, we focus on the speed limit changes on the Marginais Highways. For these particular roads, we utilize the following results: 1) the estimates of benefits on business days due to accident reductions (R$ 121.2 million for our preferred sample with matched controls) from the 2015 policy that excludes the effects of camera enforcement; 2) a range of estimates of travel time savings (R$ 25.5 million using a VTPI VOT versus R$ 56.8 million using a VOT of 50% of after-tax hourly wages) due to the 2017 speed limit reversal.[51] We estimate a benefit/cost ratio that ranges from 2.13, if we use a conservative upper bound for VOT and a lower bound for accident effects, to 4.75 if we use the (preferred) VTPI VOT and the preferred estimate of accident effects from our matched sample of segments. Appendix D provides a detailed comparison these results to other estimates of costs and benefits from van Benthem (2015) in the United States.

Next, we compare the sensitivity of our preferred results to alternative parameters for the Value of Statistical Life (VSL), which is the main driver of policy cost associated

[51]In this cost-benefit comparison, we do not include spillover effects from accidents or travel time. While we acknowledge that these effects are relevant, they are not precisely estimated in our models, particularly in the case of road accidents. The estimates also do not account for possible increases in travel time on public transit on the Marginais Highways, which account for a small share (1.7%) of public transit trips in the city. A descriptive calculation using city-wide aggregates at http://painel.scipopulis.com/ indicates an average reduction of approximately 4.6% on the average speed of buses if we compare the first half of 2016 (after the speed limit reductions) and the first half of 2015 (before the speed limit reductions). The change was larger on buses that circulate on exclusive lanes (-6.1%), and it was more limited in the case of buses that share the roads with other vehicles (-2.7%). While these differences fall within the range of our estimates of average changes in travel time as a result of the reversal, we cannot infer that they are the direct effect of the speed limit changes without disaggregate data on the speed of public buses that would allow us to account for possible confounding factors. Benefits associated with changes in accidents involving buses are captured in our analysis of accident reductions. 4.2% of victims and 6.4% of fatalities are from passengers of buses, indicating that this is a safer mode of transit that represents a limited share of the benefits from the policy.

with road accidents. Given the underlying uncertainty in this parameter and the inherent difficulty in obtaining reliable and externally valid values for VSL, we focus on identifying the breakeven VSL – the minimum VSL for which a speed limit reduction would still be socially beneficial. Figure 8 reports the results of our analysis of the breakeven VSL. VSL values are presented along the x-axis and vertical lines identify the following values: 1) the breakeven VSL for our upper bound of total policy costs where VOT is calculated at after-tax hourly wages; 2) our baseline VSL parameter of R$ 4.54 million taken from Viscusi and Masterman (2017). The horizontal lines on the graph depict the total cost of the speed limit reduction given our alternative VOT parameters.

The results of this analysis indicate that the speed limit reductions on the Marginais Highways yield positive net benefits if the value of a statistical life in our São Paulo sample is greater than R$ 0.9 million. This value is equivalent to 20% of the baseline VSL from Viscusi and Masterman (2017). However, when using the VTPI VOT parameter, the reduction in costs from non-fatal accidents alone are sufficiently large in themselves to yield positive net benefits.

4.4 Distributional Effects of Speed Limit Changes

In this final section, we use our central parameters to evaluate the distribution of policy costs and benefits across different income groups. We proxy for income using the educational attainment of commuters, which are identified in our household travel survey as well as in accident victim reports from our database of road accidents.[52] We compute the distribution of costs using a single average VOT for consistency with the VSL parameter, which is the population average for Brazil.[53]

Figure 9 plots the mean costs and benefits of the speed limit reduction for the in-

[52]While the household travel survey includes information about an individual's income, the same is not true in the case of accident reports. For that reason, we use educational attainment as the best available proxy for income. Figure A.4 in Appendix A plots the average income of adults (age > 18) from the household survey by educational attainment, illustrating the strong positive correlation between income and educational attainment in the São Paulo sample.

[53]We assume that the causal effects of the speed limit reduction on both road accidents and travel time are uniform, irrespective of an individual's educational attainment. For example, if two individuals with distinct income levels are observed making the same trip on the Marginais Highways, then we assume that their corresponding travel time after the speed limit reduction was the same.

dividuals in São Paulo as a function of educational attainment. Since groups differ in terms of total number of individuals, we present the results in per capita terms. While the benefits from accident reductions are larger for individuals with medium educational attainment (primary education, and secondary education) the travel time costs have a disproportionately larger effect on individuals with high educational attainment (college education). In the case of individuals with very-low education attainment (below primary), both the costs and benefits are small. It is likely that individuals with very low educational attainment are much less likely to have a driver's license since literacy is a regulatory requirement. To summarize, the policy delivers net benefits to low and middle income residents in São Paulo and appears to be strongly progressive.

It stands to reason that motorcyclists and pedestrians could be at greater risk on roadways in developing country cities and would therefore benefit more from policies that achieve meaningful reductions in accident risk. However, we are not aware of any theoretical result or other empirical evidence to suggest that (lower) speed limits have progressive impacts. This issue appears to have received little attention in the academic literature and in major policy discussions such as efforts relating to as the Decade of Road Safety. We investigate the mechanisms that underlie these distributional effects using two pieces of information: 1) the distribution of road accidents and fatalities by educational attainment; 2) the use of private vehicles by educational attainment. Figure 10 reports these results, which plots the proportional share of private vehicle use and road accidents in each group relative to the population of São Paulo. A negative value indicates that the share of individuals from the corresponding group is lower than the share of individuals from this group in the population. These results suggest that our finding that (lower) speed limits have strong progressive effects can be explained by: (1) the intuitive fact that a disproportionate share of the costs of longer commutes is born by higher income people who use private vehicles and main transit corridors and (2) a less intuitive fact that low and low-middle income individuals have a much higher incidence of becoming the fatal victims of road accidents. Possible explanations for the differences in fatality rates include differences in motorcycle utilization rates, differences in safety features on vehicles, and differences in driving behavior.

5 Conclusion

This paper evaluates the effect of policies that altered traffic speed limits in one of the most highly congested and dangerous cities for drivers in the world: São Paulo, Brazil. We demonstrate that a series of speed limit reductions in 2015 resulted in a substantial (29-40%) reduction in road accidents on treated road segments, resulting in approximately 1,858 averted road accidents and 97 averted fatalities within the first 18 months of adoption. Evidence from a variety of sources suggests that this reduction in accidents cannot be attributed to road substitution or other factors affecting pre-treatment accident trends. Our findings provide some evidence that camera-based enforcement augmented the effect of the speed limit change on accidents. Measurements from more than 1 million queries of trip durations using a sample of representative trips and a web API indicate that the estimated travel time for users fell by about 5.7% immediately following a speed limit increase adopted in 2017. Most of this impact on travel times affected people who travel during off-peak hours, when the speed limit change was more likely to have a binding effect on driver behavior.

Traffic safety programs and goals set by the WHO as part of the Decade of Road safety are typically motivated by concern about road accidents, without much discussion about the effects on congestion or other economic costs. The larger (and growing) fraction of damages associated with road injuries in developing country cities have made them a focus of this effort, though it is important to also address concern about the larger potential costs. In São Paulo, deep concern about the effect of speed limit reductions made this a voting issue in the Mayoral election and ultimately resulted in a reversal of the policy. This is only the second study that we are aware of that compares the benefits and costs of a speed limit change and the first to do so in a developing country city. We combine our reduced form results with standard parameters from the literature to compare the costs and benefits of the speed limit reduction adopted in the city urban highways in

2015. Our estimates indicate that the benefits of the policy outweighed the costs even in our most conservative choice of parameters. Our study provides evidence that speed limit reductions can be rationalized even within cities that are concerned about additional congestion problems.

Using information about the educational attainment of accident victims and a travel survey that provides detailed information about the types of individuals who were affected by the policies, we find evidence that the speed limit reduction likely had strongly progressive impacts. While increased travel times facing car trips on São Paulo's main highways disproportionately affect wealthier individuals, the reduction in fatal accidents disproportionately benefited lower- and middle-income groups. This effect is particularly strong for pedestrians and motorcyclists, which is the largest group of victims of fatal road accidents in Brazil. Among residents with less than primary education, fatal road accidents in São Paulo are a key contributor to unnatural deaths, representing as large a threat as violence (each of these causes accounts for roughly 20% of unnatural deaths). Our findings suggest that road safety policies such as speed limit reductions have had a considerably larger effect on fatalities than gun control and other policies aimed to reduce violent crimes and have particular benefits for reducing the fatality risk of the urban poor.

Our analysis is limited in several respects. Our representative sample of trips constrains our analysis to trips made by residents on business days, so we do not account for policy impacts on freight transportation and trips made by non-residents. Therefore, we may not be accounting for an important share of social costs associated with a speed limit reduction. We do not find any evidence of policy effects on pollution using data from monitoring stations in São Paulo. The external validity of our results is clearly limited given that we study a single city. Our reduced-form results are surprisingly consistent with those reported for interstate highways in the United States (van Benthem, 2015). Several cities throughout the world are experimenting with stricter speed limit policies and the United Nations has highlighted policy impact evaluation as a goal of the Decade of Road Safety program. This paper suggests that careful evaluation of policy experiments can yield rich and nuanced information about effectiveness, enforcement, benefits, and the distributional implications of driving regulations. We emphasize the potential value of broader comparison of outcomes similar to the ones obtained in our study to evaluate the heterogeneity of policy impacts in different programs and cities.

References

Abraham, S. and L. Sun (2018). Estimating Dynamic Treatment Effects in Event Studies with Heterogeneous Treatment Effects. Working Paper.

Akbar, P. and G. Duranton (2017). Measuring the Cost of Congestion in Highly Congested City: Bogotá. Working Paper. CAF Development Bank Of Latinamerica.

Akbar, P. A., V. Couture, G. Duranton, E. Ghani, and A. Storeygard (2018). Mobility and congestion in urban India. Working Paper. World Bank Group.

Archer, J., N. Fotheringham, M. Symmons, and B. Corben (2008). The impact of lowered speed limits in urban and metropolitan areas. Technical Report. Monash University Accident Research Centre, Victoria, Australia.

Ashenfelter, O. and M. Greenstone (2004). Using Mandated Speed Limits to Measure the Value of a Statistical Life. *Journal of Political Economy 112*(S1), S226–S267.

Bel, G., C. Bolancé, M. Guillén, and J. Rosell (2015). The environmental effects of changing speed limits: A quantile regression approach. *Transportation Research Part D: Transport and Environment 36*, 76 – 85.

Borusyak, K. and X. Jaravel (2016). Revisiting Event Study Designs. Working Paper.

Cabral, M. V. d. F. (2016). Avaliação do impacto do INFOCRIM sobre as taxas de homicídios dos municípios paulistas: uma aplicação do método de diferenças em diferenças espacial. Doctoral Thesis, Universidade Federal de Juiz de Fora (UFJF).

Campos, V. R., R. d. S. e Silva, S. Duailibi, J. F. dos Santos, R. Laranjeira, and I. Pinsky (2013). The effect of the new traffic law on drinking and driving in São Paulo, Brazil. *Accident Analysis & Prevention 50*, 622–627.

CET (2016). Benefícios Imediatos da Redução das Velocidades Máximas Permitidas. O Caso das Marginais Tietê e Pinheiros. Technical Report. NT 251.

CET (2017). Acidentes de Trânsito – Relatório Anual - 2016. Technical Report.

DATASUS (2018). Informações de saúde (tabnet). Online. www2.datasus.gov.br/DATASUS.

dos Santos, M. J. and A. L. Kassouf (2013). A cointegration analysis of crime, economic activity, and police performance in São Paulo city. *Journal of Applied Statistics 40*(10), 2087–2109.

Elvik, R. (2013). A before-after study of the effects on safety of environmental speed limits in the city of Oslo, Norway. *Safety Science 55*, 10–16.

Folgero, I. K., T. Harding, and B. Westby (2017). Going Fast or Going Green? Evidence from Environmental Speed Limits in Norway. Institutt for Samfunnsøkonomi, NHH.

Google (2009). Google official blog. Online. goo.gl/4rsyar.

Hanna, R., G. Kreindler, and B. A. Olken (2017). Citywide effects of high-occupancy vehicle restrictions: Evidence from "three-in-one" in Jakarta. *Science 357*(6346), 89–93.

IPEA (2016). Estimativa dos Custos dos Acidentes de Trânsito no Brasil com Base na Atualização Simplificada das Pesquisas Anteriores do Ipea. Technical Report.

Jardim, F. B. (2017). Estimando o impacto da redução da velocidade máxima nas vias de São Saulo e o valor estatístico de uma vida. Master Thesis, FGV-EPGE.

Li, H. and D. J. Graham (2016). Quantifying the causal effects of 20 mph zones on road casualties in London via doubly robust estimation. *Accident Analysis & Prevention 93*, 65–74.

METRO (2013). Síntese das Informações - Pesquisa Domiciliar. Technical Report.

Musicant, O., H. Bar-Gera, and E. Schechtman (2016). Impact of Speed Limit Change on Driving Speed and Road Safety on Interurban Roads: Meta-Analysis. *Transportation Research Record: Journal of the Transportation Research Board* (2601), 42–49.

NYC (2018). Vision Zero Year Four Report. Technical Report. New York City Mayor's Office of Operations.

OECD/ECMT (2006). Speed Management. Technical Report.

OECD/ITF (2018). Speed and Crash Risk. Technical Report.

Parry, I. W. and K. A. Small (2005). Does Britain or the United States Have the Right Gasoline Tax? *American Economic Review 95*(4), 1276–1289.

Parry, I. W., M. Walls, and W. Harrington (2007). Automobile Externalities and Policies. *Journal of economic literature 45*(2), 373–399.

Pauw, E. D., S. Daniels, M. Thierie, and T. Brijs (2014). Safety effects of reducing the speed limit from 90km/h to 70km/h. *Accident Analysis Prevention 62*, 426–431.

Rode, P., R. Burdett, R. Brown, F. Ramos, K. Kitazawa, A. Paccoud, and N. Tesfay (2009). Cities and social equity: inequality, territory and urban form. Technical Report. Urban Age Programme, London School of Economics and Political Science.

Sayed, T. and E. Sacchi (2016). Evaluating the safety impact of increased speed limits on rural highways in British Columbia. *Accident Analysis & Prevention 95*, 172–177.

Schneider, R. (2018). Crime and political effects of a concealed weapons ban in brazil. Working Paper.

USDOT. The Value of Travel Time Savings: Departmental Guidance for Conducting Economic Evaluations Revision 2 (2014 update). Technical Report.

Vadeby, A. and Å. Forsman (2017). Traffic safety effects of new speed limits in Sweden. *Accident Analysis & Prevention*.

van Benthem, A. (2015). What is the optimal speed limit on freeways? *Journal of Public Economics 124*, 44–62.

Viscusi, W. K. and C. J. Masterman (2017). Income Elasticities and Global Values of a Statistical Sife. *Journal of Benefit-Cost Analysis 8*(2), 226–250.

VTPI (2016). Transportation Cost and Benefit Analysis Techniques, Estimates and Implications [Second Edition]. Online Guidebook. www.vtpi.org/tca/.

WHO (2015). Global status report on road safety 2015. Technical Report.

Wilmot, C. G. and M. Khanal (1999). Effect of speed limits on speed and safety: A review. *Transport Reviews 19*(4), 315–329.

Wolff, H. (2014). Value of time: Speeding behavior and gasoline prices. *Journal of Environmental Economics and Management 67*(1), 71–88.

Woolley, J. (2005). Recent advantages of lower speed limits in australia. *Journal of the Eastern Asia Society for Transportation Studies 6*, 3562–3573.

Tables

Table 1. Traffic Accidents per Year in São Paulo by Road Type (2012-2017)

	Total	2012	2013	2014	2015	2016	2017
São Paulo							
Accidents	125,769	26,928	25,501	23,547	20,258	16,052	13,483
Injured Victims	152,970	33,539	31,086	28,616	24,239	19,239	16,251
pedestrians	34,572	7,756	7,198	6,480	5,391	4,135	3,612
motorcyclists	82,951	17,485	16,777	15,707	13,258	10,682	9,042
Fatalities	5,997	1,160	1,068	1,177	941	855	796
pedestrians	2,526	494	460	517	382	341	332
motorcyclists	2,619	494	468	495	424	376	362
Marginais Highways							
Accidents	5,016	1,039	1,044	1,168	787	509	469
Injured Victims	6,102	1,285	1,266	1,401	950	631	569
pedestrians	465	102	94	107	75	37	50
motorcyclists	3,880	765	803	931	629	396	356
Fatalities	276	53	44	63	50	29	37
pedestrians	77	16	14	22	10	5	10
motorcyclists	140	24	16	32	25	18	25
Treated Arterial Roads [a]							
Accidents	41,524	8,826	8,712	8,233	6,869	4,916	3,968
Injured Victims	50,698	11,075	10,689	10,019	8,276	5,888	4,751
pedestrians	9,970	2,194	2,181	1,948	1,604	1,141	902
motorcyclists	28,685	6,065	6,021	5,690	4,728	3,430	2,751
Fatalities	1,960	399	354	390	286	282	249
pedestrians	801	161	144	165	117	125	89
motorcyclists	845	168	154	147	134	129	113
Non-Treated Avenues and Express Roads [b]							
Accidents	47,404	10,027	9,320	8,420	7,619	6,564	5,454
Injured Victims	57,979	12,551	11,411	10,286	9,140	7,925	6,666
pedestrians	14,204	3,178	2,857	2,616	2,195	1,787	1,571
motorcyclists	30,986	6,430	6,018	5,548	4,850	4,398	3,742
Fatalities	2,242	411	388	457	347	332	307
pedestrians	956	184	170	203	141	124	134
motorcyclists	1,011	189	177	203	146	150	146

Notes: This table was created based on the datasets of road accidents compiled by the São Paulo Transit Agency (CET). These datasets were obtained by the authors through a series of LAI (Lei de Acesso à Informacão) requests. Accidents were matched to road segments using a threshold distance of 100m to the segments' shapefiles. [a] Treated arterial roads are all arterial roads that had the speed limit reduced in 2015. [b] Non-treated avenues and express roads is the subset of non-treated road segments used to construct the control group in our empirical analysis. Besides the three subgroups listed here, the total number of accidents in the city of São Paulo also includes accidents on smaller local roads, which account for approximately 25.3% of all accidents.

Table 2. Trips Simulated Using Google Directions API

	All Crawled Trips				Trips Using Marginais Highways[c]			
	Obs. (Thousand)	Share	mean	s.d.	Obs. (Thousand)	Share	mean	s.d.
Crawled Trips[a]	1,471.6	1.00			243.7	1.00		
Post Speed Limit Increase[b]	511.5	0.35			84.8	0.35		
Peak	562.2	0.38			96.8	0.40		
Rain	93.6	0.06			15.6	0.06		
Use Marginais Highways[c]	243.7	0.17			243.7	1.00		
Travel Time[d] (Minutes)			20.00	17.11			38.42	19.83
Travel Length[d] (KM)			8.31	9.18			18.49	12.24
Percent on Marginais[c]			0.04	0.12			0.22	0.21

Notes: [a] Crawled Trips are private vehicle trips reported in the 2012 São Paulo Mobility Household Survey that were scraped on Google Directions API between July 4, 2016 and September 1, 2017. The survey data include the exact origin and destination coordinates of trips and their departure time. We used that information to daily query trips in a 4 hour intervals around the original departure time. [b] The speed limit increase in the Marginais Highways was implemented in January 25, 2017. [c] We identify trips that use the Marginais Highways by comparing the intersection between the optimal trip path suggested by OSRM API and a buffer of 200m around the Marginais shapefile. All trips with more than 400m of intersection between the optimal path and the buffer are defined as running through the Marginais Highways. [d] Estimated travel time under real-time traffic conditions and travel distance are reported by Google Directions API for each query.

Table 3. Traffic Control Cameras and Tickets in São Paulo (2014-2017)

	Total	Year			
		2014	2015	2016	2017
A: São Paulo					
Cameras	837	385	734	798	837
Tickets (million)	38.0	6.21	9.61	12.09	10.07
Driving Restriction	9.9	1.76	2.41	3.02	2.69
Speeding	20.5	3.11	5.13	6.74	5.56
Other	7.6	1.34	2.07	2.33	1.81
B: Marginais Highways					
Cameras	98	15	59	81	98
Tickets (million)	9.70	1.40	2.50	3.61	2.19
Driving Restriction	2.31	0.32	0.55	0.77	0.67
Speeding	5.04	0.57	1.33	2.06	1.07
Other	2.34	0.51	0.61	0.78	0.44

Notes: Table created by the authors based on data scraped from the website Painel de Mobilidade Segura (http://mobilidadesegura.prefeitura.sp.gov.br), which is maintained by the São Paulo Transit Agency (CET). In the case of cameras, the numbers indicate the maximum number of unique camera locations in any specific month. We use that metric because some camera locations are discontinued or the equipment is moved to other locations, so the total number of unique camera locations does not necessarily indicate the total number of cameras monitoring traffic in a given period.

Table 4. Effect of Speed Limit Reduction and Camera Enforcement on Road Accidents

	Dependent variable: number of accidents per segment per month				
	Sample of segments:				
	(1)	(2)	(3)	(4)	(5)
Quarters after speed limit reduction					
1	-0.091 **	-0.147 ***	-0.156 ***	-0.165 ***	-0.184 ***
	(0.032)	(0.035)	(0.040)	(0.034)	(0.037)
2	-0.150 ***	-0.205 ***	-0.218 ***	-0.218 ***	-0.202 ***
	(0.032)	(0.036)	(0.041)	(0.035)	(0.040)
3	-0.108 **	-0.173 ***	-0.181 ***	-0.187 ***	-0.200 ***
	(0.037)	(0.041)	(0.048)	(0.042)	(0.042)
4	-0.112 **	-0.191 ***	-0.193 ***	-0.211 ***	-0.288 ***
	(0.039)	(0.044)	(0.056)	(0.045)	(0.035)
5	-0.223 ***	-0.296 ***	-0.312 ***	-0.311 ***	-0.416 ***
	(0.037)	(0.041)	(0.050)	(0.041)	(0.032)
≥6	-0.186 ***	-0.279 ***	-0.312 ***	-0.289 ***	-0.380 ***
	(0.026)	(0.032)	(0.042)	(0.032)	(0.034)
Camera on segment					
camera	-0.034	-0.004	0.000	-0.007	0.017
	(0.029)	(0.032)	(0.034)	(0.032)	(0.034)
camera × speed limit reduction	-0.086	-0.106 *	-0.098 *	-0.100 *	-0.116 *
	(0.048)	(0.047)	(0.049)	(0.048)	(0.047)
Treatment group	All treated arterial and highways	All treated arterial and highways	Treated arterial and highways w/ >11 accidents	Matched arterial and highways	All treated arterial and highways
Control group	All non-treated avenues	Non-treated ave. >1.6km away from treatment	Non-treated ave. >1.6km away from treatment, >11 accidents	Non-treated ave., >1.6km away from treatment, matched to treatment segm.	None
Segment FE	Yes	Yes	Yes	Yes	Yes
Year-month FE	Yes	Yes	Yes	Yes	No
Parametric funct. form	No	No	No	No	Yes
Observations	424,356	213,108	105,243	202,758	109,572

Notes: Standard Errors are clustered by road (202 clusters). All specifications were estimated using a Poisson regression model with coefficients reported as relative incidence ratios. For instance, a coefficient of 0.1 indicates a 10% larger incidence of accidents. All specifications were estimated using a monthly panel of road segments, however specifications differ w.r.t. the observations that were included in each regression. Specifications (1)-(4) use different sets of treated highways and arterial roads, and non-treated avenues. Specification (5) only includes treated segments. Specifications (1)-(4) include monthly fixed effects, and specification (5) uses a parametric functional form that includes a linear time trend and two citywide covariates (fuel sales and total number of cameras).

Table 5. Effect of Speed Limit Reductions on Traffic Tickets

	Type of Ticket		
	Speeding	Driving Restriction	Other Tickets
Quarters after Speed Limit Reduction			
1	0.814 ***	-0.061	-0.121
	(0.059)	(0.038)	(0.066)
2	0.831 ***	-0.035	0.032
	(0.068)	(0.044)	(0.078)
3	0.818 ***	0.012	0.045
	(0.071)	(0.046)	(0.084)
4	0.770 ***	-0.026	0.071
	(0.073)	(0.047)	(0.086)
5	0.751 ***	-0.013	-0.016
	(0.072)	(0.047)	(0.086)
6	0.750 ***	-0.020	0.000
	(0.062)	(0.042)	(0.078)
Month Fe	Yes	Yes	Yes
Segment FE	Yes	Yes	Yes
Obs.	3,240	2,160	2,124

Notes: The dependent variables in the regressions are the log of the number of tickets issued by cameras that were continuously active between January 2015 and December 2017. Coefficients indicate relative changes in the number of tickets issued by cameras located on treated segments if compared to non-treated ones.

Table 6. Effects of Speed Limit Changes on the Marginais Highways

	Dependent variable: number of accidents per segment per month				
	Sample of segments:				
	(1)	(2)	(3)	(4)	(5)
Speed limit reduction (SLR)					
Marginais highways 6th quarter after SLR	-0.347 **	-0.401 ***	-0.405 ***	-0.407 ***	-0.502 ***
	(0.110)	(0.103)	(0.112)	(0.103)	(0.083)
Arterial Roads 6th quarter after SLR	-0.197 ***	-0.287 ***	-0.316 ***	-0.294 ***	-0.391 ***
	(0.023)	(0.030)	(0.037)	(0.030)	(0.029)
Speed limit increase (SLI)					
Marginais highways 4th quarter after SLI	0.169	0.142	0.122	0.130	0.133
	(0.181)	(0.180)	(0.186)	(0.181)	(0.172)
Treatment group	All treated arterial and highways	All treated arterial and highways	Treated arterial and highways w/ >11 accidents	Matched arterial and highways	All treated arterial and highways
Control group	All non-treated avenues	Non-treated ave. >1.6km away from treatment	Non-treated ave. >1.6km away from treatment, >11 accidents	Non-treated ave., >1.6km away from treatment, matched to treatment segm.	None
Segment FE	Yes	Yes	Yes	Yes	Yes
Year-month FE	Yes	Yes	Yes	Yes	No
Parametric funct. form	No	No	No	No	Yes
Observations	424,356	213,108	105,243	202,758	109,572

Notes: Standard Errors are clustered by road (202 clusters) All specifications were estimated using a Poisson regression model with coefficients reported as relative incidence ratios. For instance, a coefficient of 0.1 indicates a 10% larger incidence of accidents. All specifications were estimated using a monthly panel of road segments, however specifications differ w.r.t. the observations that were included in each regression. Specifications (1)-(4) use different sets of treated highways and arterial roads, and non-treated avenues. Specification (5) only includes treated segments. Specifications (1)-(4) include monthly fixed effects, and specification (5) uses a parametric functional form that includes a linear time trend and two citywide covariates (fuel sales and total number of cameras).

Table 7. Effects of Marginais Speed Limit Increase (2017) on Travel Times

	Changes in Estimated Travel Time			
	(1)	(2)	(3)	(4)
Post SLI - Ratio at Marg.	-0.065 ***	-0.058 ***	-0.057 ***	
	(0.014)	(0.013)	(0.013)	
Post SLI - Ratio at Marg. - Peak				-0.027
				(0.025)
Post SLI - Ratio at Marg. - Off-Peak				-0.075 ***
				(0.011)
Post SLI	-0.018 ***	-0.011 ***		
	(0.004)	(0.003)		
Post SLI - Ratio at 1km of Marg.		-0.034 ***	-0.035 ***	-0.034 ***
		(0.008)	(0.008)	(0.008)
Post SLI - Ratio at 3km of Marg.		-0.016 **	-0.015 **	-0.015 **
		(0.005)	(0.005)	(0.005)
Post SLI - Ratio at 5km of Marg.		-0.009	-0.008	-0.008
		(0.004)	(0.005)	(0.005)
Rain	0.019 ***	0.019 ***	0.022 ***	0.022 ***
	(0.005)	(0.005)	(0.005)	(0.005)
Holiday	-0.100 ***	-0.100 ***	-0.096 ***	-0.096 ***
	(0.009)	(0.009)	(0.010)	(0.010)
Trip-Hour FE	Yes	Yes	Yes	Yes
Month FE	No	No	Yes	Yes
Obs.	1,337,555	1,337,555	1,337,555	1,337,555

Notes: Standard Errors are clustered by date (191 clusters). Coefficients indicate the average changes of dependent variables with respect to pre-treatment means. For example, a coefficient of -0.5 indicates a reduction of 50%. Post SLI is a dummy that indicates queries made after the speed limit increase on the Marg. in January 25, 2017. Rain is a dummy indicating if there was positive registers of rain during the hour of each query was made. Trip-Hour Fixed effects include a specific intercept for each pair of origin and destination coordinates queried in a certain hour of the day.

Table 8. Policy Benefits from Accident Reductions

	Per Year			Business Days Only		
	All Treated Roads	Marginais Highways	Arterial Roads	All Treated Roads	Marginais Highways	Arterial Roads
Baseline period						
Accidents	8,925	1,052	7,873	6,422	801	5,621
Cost (BRL Million)	2,948.2	413.4	2,534.8	1,854.2	281.4	1,572.8
Policy Scenarios - Coefficients from Sample (4)						
Speed Limit Reduction (SLR)						
Accidents	6,048	596	5,452	4,345	454	3,891
Cost (BRL Million)	1,998.2	236.4	1,761.7	1,252.3	160.2	1,092.1
Policy Benefits (BRL Million)	950.0	177.0	773.0	601.9	121.2	480.7
SLR and Camera Expansion						
Accidents	5,864	561	5,303	4,212	427	3,786
Cost (BRL Million)	1,941.9	225.0	1,716.8	1,217.2	153.3	1,063.9
Policy Benefits (BRL Million)	1,006.3	188.4	817.9	637.0	128.1	508.9
Policy Scenarios - Coefficients from Sample (5)						
Speed Limit Reduction						
Accidents	5,181	495	4,686	3,721	377	3,344
Cost (BRL Million)	1,712	197	1,515	1,072.5	133.3	939.2
Policy Benefits (BRL Million)	1,236.0	216.5	1,019.5	781.7	148.1	633.7
SLR and Camera Expansion						
Accidents	4,993	460	4,534	3,586	349	3,236
Cost (BRL Million)	1,655	185	1,469	1,037	126	910
Policy Benefits (BRL Million)	1,293.6	228.1	1,065.5	817.7	155.1	662.6

Notes: The baseline corresponds to the year immediately before the first banners and signs were placed announcing the speed limit reductions in the Marginais Highways. That is, from the second quarter of 2014 to the first quarter of 2015. Policy scenarios were constructed based on the long term policy effects from the empirical model estimated from samples (4) and (5). The first scenario assumes a speed limit reduction on all treated roads but keeps constant the number of cameras. The second scenario considers an expansion in the number of cameras equal to that observed in 2015. Accident costs are calculated using parameters from IPEA (2016) and the value of statistical life calculated by Viscusi and Masterman (2017) for Brazil.

Table 9. Benefits of Travel Time Reductions (Speed Limit Increase of 2017)

Scenarios[a]	Cost of Time Spent in Traffic (BRL Million)							
	VOT = After-Tax Wages				VOT = VTPI guidelines			
	Total	Marginais	Spillover Area	Other Roads	Total	Marginais	Spillover Area	Other Roads
Observed								
Observed Costs	15,361.6	1,170.6	3,261.3	10,929.7	6,286.1	524.5	1,327.0	4,434.5
SLI Marginais + Spillovers								
Counterfactual Costs	15,226.8	1,113.8	3,183.3	10,929.7	6,228.9	499.1	1,295.3	4,434.5
Policy Benefits	134.8	56.8	78.0	-	57.2	25.5	31.7	-
SLI Effects - Marginais Only								
Counterfactual Costs	15,304.8	1,113.8	3,261.3	10,929.7	6,260.6	499.1	1,327.0	4,434.5
Policy Benefits	56.8	56.8	-	-	25.5	25.5	-	-

Notes: All scenarios use survey expansion factors to recover the population of trips made by private vehicle on all business days of a given year. Counterfactual scenarios are based on our empirical estimates of policy impacts. All values are converted to BRL of 2016 by the IBGE IPCA inflation index.

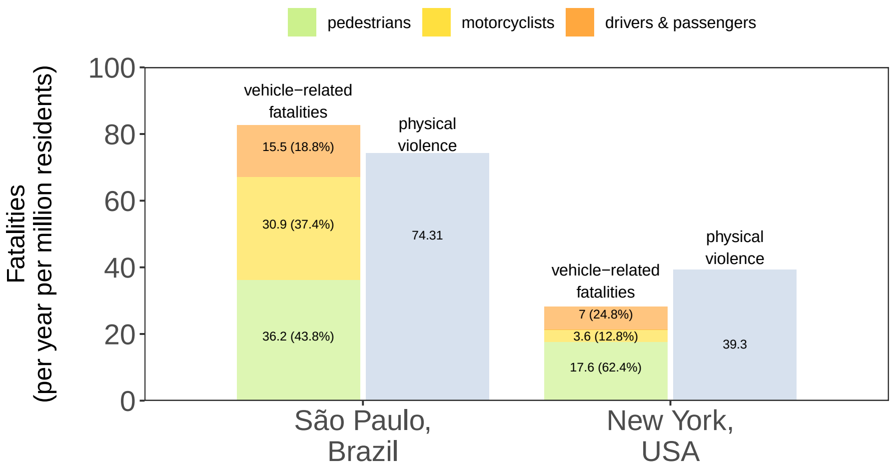
Table 10. Comparison of Travel Time Gains: Individual-Specific vs Average VOT

Scenarios[a]	Cost of Time Spent in Traffic (BRL Million)							
	VOT = After-Tax Wages				VOT = Median After-Tax Wage			
	Total	Marginais	Spillover Area	Other Roads	Total	Marginais	Spillover Area	Other Roads
Observed								
Observed Costs	15,361.6	1,170.6	3,261.3	10,929.7	11,708.2	773.3	2,131.7	8,803.2
SLI Marginais + Spillovers								
Counterfactual Costs	15,304.8	1,113.8	3,261.3	10,929.7	11,670.6	735.7	2,131.7	8,803.2
Policy Benefits	56.8	56.8	-	-	37.5	37.5	-	-
SLI Effects - Marginais Only								
Counterfactual Costs	15,226.8	1,113.8	3,183.3	10,929.7	11,619.7	735.7	2,080.7	8,803.2
Policy Benefits	134.8	56.8	78.0	-	88.5	37.5	51.0	-

Notes: All scenarios use survey expansion factors to recover the population of trips made by private vehicle on all business days of a given year. Counterfactual scenarios are based on our empirical estimates of policy impacts. All values are converted to BRL of 2016 by the IBGE IPCA inflation index.

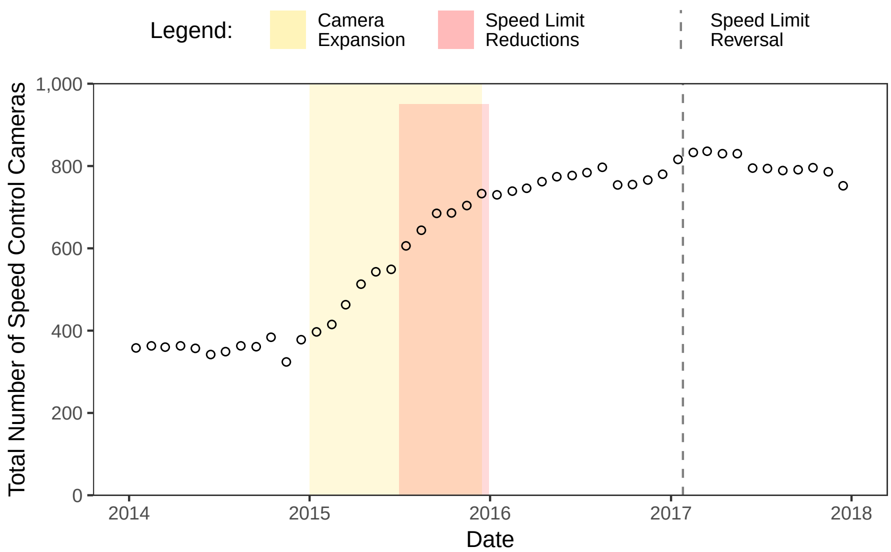
Figures

Figure 1. Road Fatalities and Homicides per Million Residents: São Paulo vs. New York



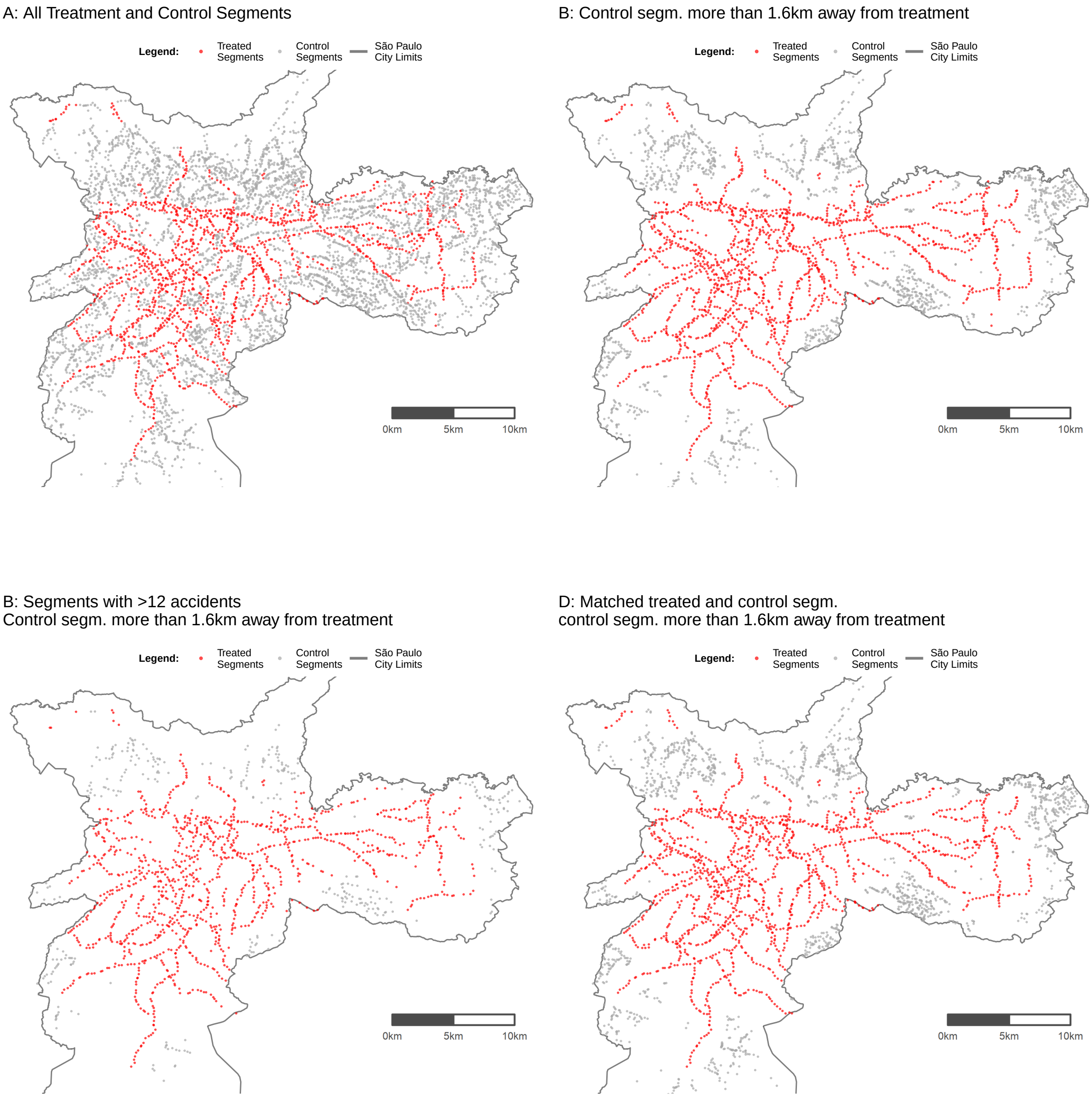
Notes: Data for New York is from the City's Vision Zero Four Year Report (NYC, 2018) and the NYPD Crime and Enforcement Activity Reports. Data for São Paulo comes from reports of road accidents compiled by the Transit Agency of São Paulo (CET, 2017) and the SSP-SP statistical data website.

Figure 2. Growth of Speed Control Cameras in São Paulo



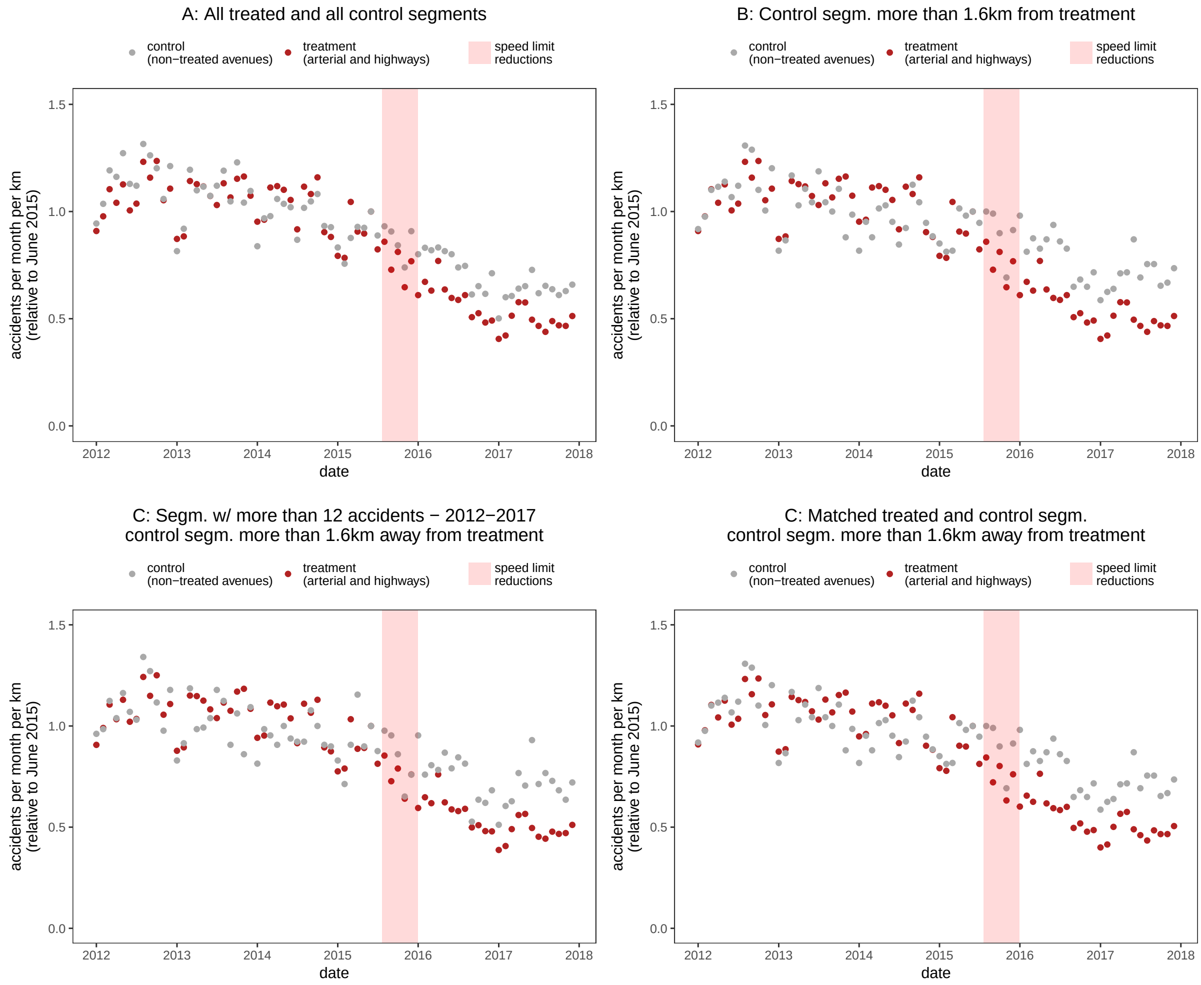
Notes: Monthly observations of speed monitoring cameras compiled from the website Painel de Mobilidade Segura (http://mobilidadesegura.prefeitura.sp.gov.br), which is maintained by the São Paulo Transit Agency (CET).

Figure 3. Treatment and Control Road Segments Used in Empirical Specifications



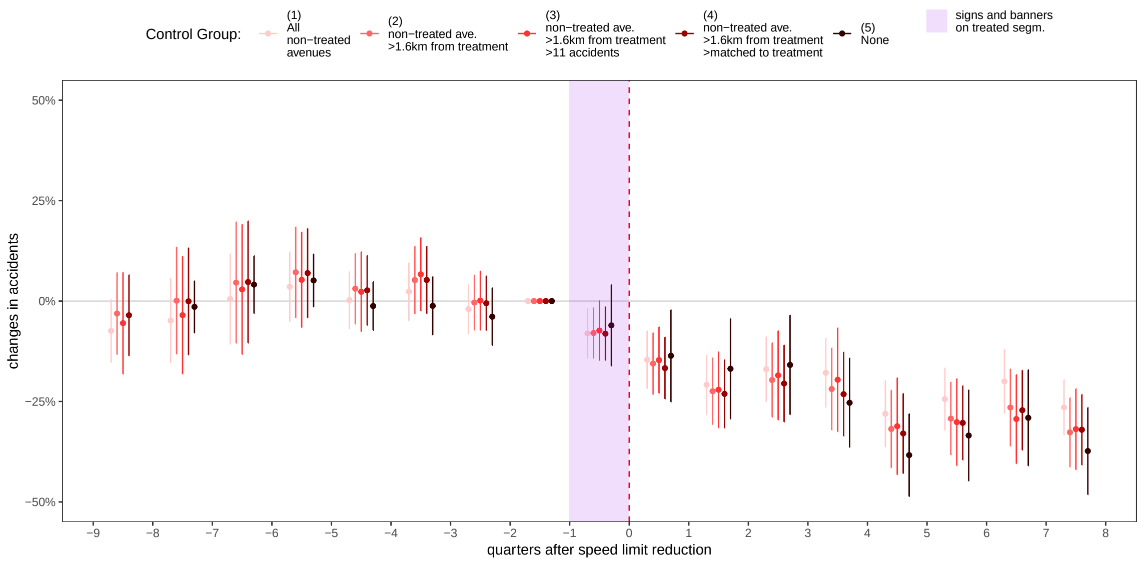
Notes: Treated Segments include all arterial roads and highways where speed limits were reduced in 2015. In Panel A, the control group includes all non-treated avenues and express roads in São Paulo. In Panel B, the control segments are restricted to segments that are more than 1,600m away from any treated road. In Panel C, the treated and control segments included in Panel B are further restricted to the segments with 12 or more accidents in the period of 2012 to 2017, where 12 is the mean number of accidents per segment. Panel D restricts the control segments included in panel B using a matching procedure based on total accidents per segment before the beginning of the treatment period.

Figure 4. Road Accidents Occurring on Treated and Control Segments (2012-2017)



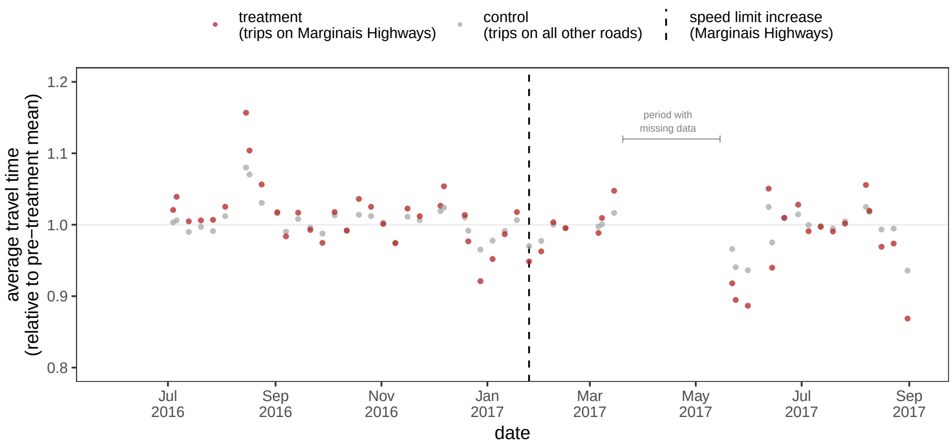
Notes: Each point represents the average number of accidents per km on treatment or control segments in a given calendar month. Treated Segments include all arterial roads and highways where speed limits were reduced in 2015. In Panel A, the control group includes all non-treated avenues and express roads in São Paulo. In Panel B, both the treatment and control groups were reduced to segments with more than 20 accidents in the whole period. In Panel C, the treatment group includes all treated segments. The control group was restricted with a one-to-one match based on total accidents per segment before the beginning of the treatment period.

Figure 5. Speed Limit Reductions: Pre-Treatment Trends in Accidents



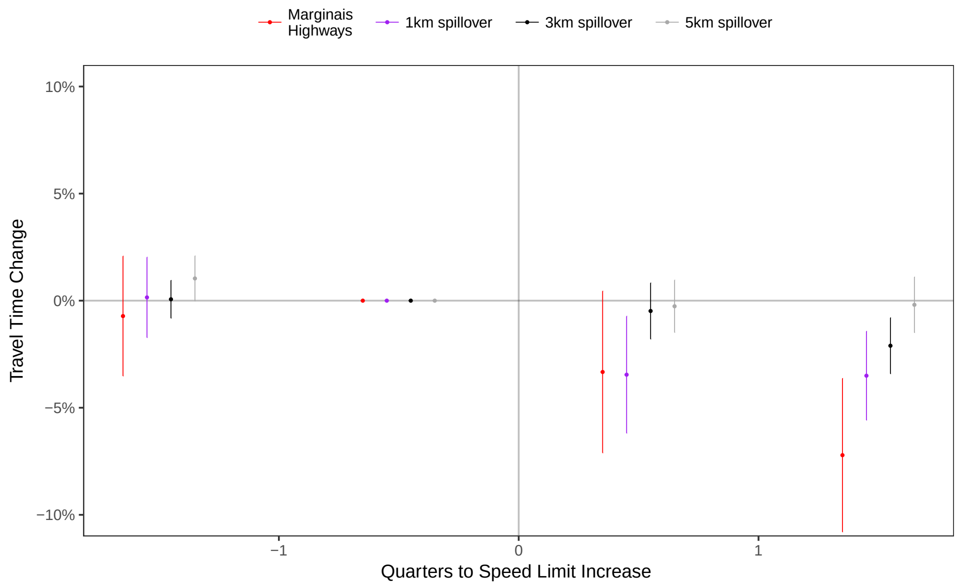
Notes: All specifications were estimated using a Poisson regression model with coefficients reported as relative incidence ratios. For instance, a coefficient of 0.1 indicates a 10% larger incidence of accidents. All specifications were estimated using a monthly panel of road segments, however specifications differ w.r.t. the observations that were included in each regression. Specifications (1)-(4) use different sets of treated highways and arterial roads, and non-treated avenues. Specification (5) only include treated segments. Specifications (1)-(4) include monthly fixed effects, and specification (5) uses a parametric functional form that includes a linear time trend and two citywide covariates (fuel sales and total number of cameras).

Figure 6. Average Duration of Queried Trips (by week)



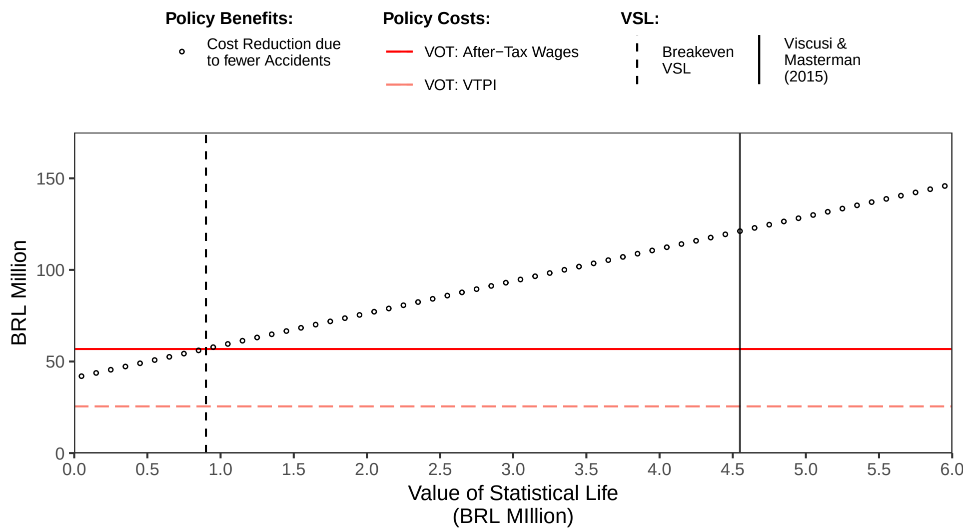
Notes: Each point corresponds to the average estimated travel time of crawled trips relative to its corresponding pre-treatment mean. Due to a server failure, our web-crawler was inactive between March 15, 2017 and May 21, 2017. Therefore, data from that period is missing from the series.

Figure 7. Effect of Speed Limit Increase on Travel Times (Marginais Highways)



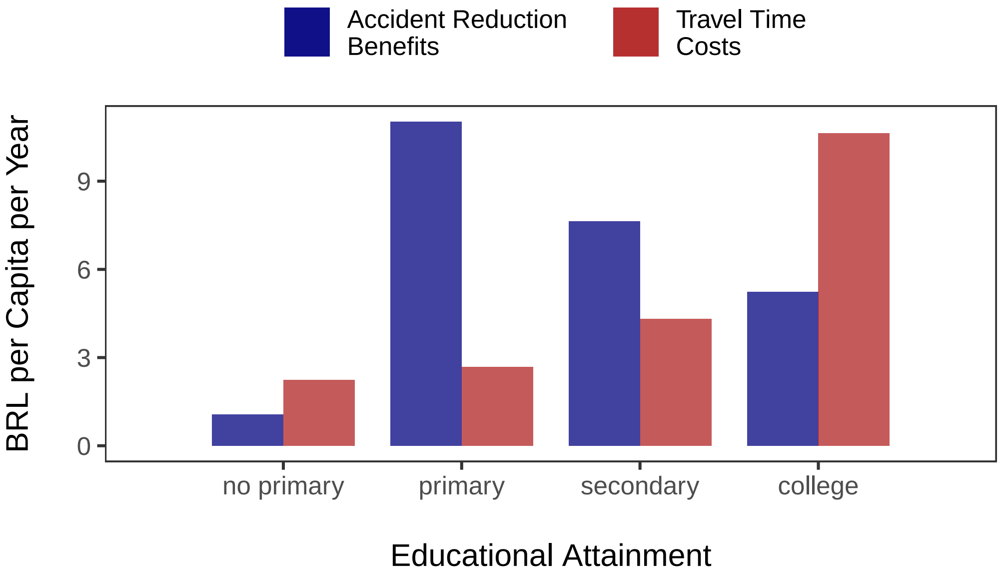
Notes: Coefficients correspond to relative changes in travel time relative to trips completely made beyond 5 km away from the Marginais highways.

Figure 8. Cost-Benefit Analysis: Sensitivity to VSL Estimates



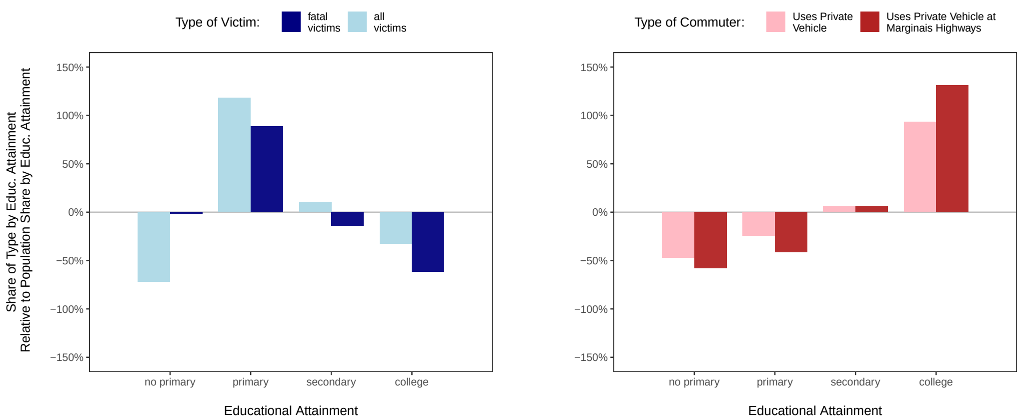
Notes: The figure plots the estimated total policy benefits given alternative values for the VSL parameter. These results are represented by the dotted diagonal line in the Figure. The horizontal lines indicate the total policy cost due to longer commutes under alternative values for the VOT paramenter. Tho solid red line shows total policy costs in the case where VOT is equal to 50% of individuals' after tax wages. The dashed red line indicates total policy costs if VOT is calculated using the VTPI guidelines where the value varies by trip motivation. The vertical are key values for the VSL parameter. The solid black line indicates our baseline value that was calculated by Viscusi and Masterman (2017). The dashed vertical black line is the breakeven VSL for which policy costs equal policy benefits under the highest VOT parameter.

Figure 9. Distributional Effects of Speed Limit Reductions



Notes: The distribution of benefits by educational attainment due to fewer accidents is assumed to be proportional to the distribution of accidents costs in the baseline period. Travel time costs were assumed to be proportional to the highway share of each representative trip made by private vehicle. To make the distribution of costs and benefits comparable, we assume all individuals have the same VOT and the same VSL, which are computed using the average for the total adult population.

Figure 10. Private Vehicle Utilization and Accidents by Educational Attainment



Notes: The Y-axis indicates the difference between the share of individuals in each educational attainment group by type relative to the share of each educational group in the population. For example, a value of 50% for fatal victims for the individuals with primary educational attainment indicate that the share of fatal victims with primary educational attainment is 50% larger than the share of individuals with primary educational attainment in the whole population.

Appendices

A Data appendix

A.1 Data: Treated Road Segments

To construct our panel of treated road segments, we extensively reviewed the online newsletter of the São Paulo Traffic Agency (http://www.cetsp.com.br/noticias). When the program of speed limit reductions was ongoing, the Agency would post in the newsletter all the upcoming changes that would be adopted in the following days. Table A.1 summarizes all reports we identified in the newsletter that were informing about speed limit changes that took place in 2015 and that were used in our analyses. Additionally, Figure A.1 shows in further details one of these reports. It specifies the date when the change would be implemented, the previous and the new speed limits, and the exact road segments that would be affected by the change.

Based on the information collected from these reports, we constructed a shapefile of treated road segments including the date of treatment and the type of change associated with each road. Figure A.2 maps all treated roads in São Paulo highlighting the Marginais Highways where speed limit was reduced from 90 km/h to 70 km/h. Figure A.3 shows the total length of treated segments throughout the second half of 2015. It is worth noting that policy implementation was evenly distributed throughout that period.

Table A.1. 2015 Speed Limit Change Reports

Announcement Date	Speed Limit Change Date	Treated Roads	Link
7/8/2015	7/20/2015	AV MARGINAL DO RIO TIETE, AV MARGINAL DO RIO TIETE	http://www.capital.sp.gov.br/noticia/velocidade-maxima-das-marginais-sera-reduzida-a
7/30/2015	8/3/2015	AV JACU-PESSEGO, AV JACU-PESSEGO	http://www.cetsp.com.br/noticias/2015/07/30/programa-de-protecao-a-vida-cet-implanta-reducao-de-velocidade-na-avenida-jacu-pessego.aspx
7/30/2015	8/3/2015	AV ARICANDUVA, VD ENG ALBERTO BADRA	http://www.cetsp.com.br/noticias/2015/07/30/programa-de-protecao-a-vida-cet-implanta-reducao-de-velocidade-na-avenida-aricanduva.aspx
7/30/2015	8/3/2015	AV S JOAO, AV GAL OLIMPIO DA SILVEIRA, RUA AMARAL GURGEL	http://www.cetsp.com.br/noticias/2015/07/30/programa-de-protecao-a-vida-cet-implanta-reducao-de-velocidade-no-eixo-sao-joao-olimpio-da-silveira-amaral-gurgel.aspx
8/12/2015	8/17/2015	AV ANGELICA, AV ANGELICA, AV NADIR DIAS DE FIGUEIREDO, RUA MAJ NATANAEL, AV DR ABRAAO RIBEIRO, AV PACAEMBU	http://www.cetsp.com.br/noticias/2015/08/12/cet-implanta-cet-implanta-reducao-de-velocidade-maxima-em-mais-duas-vias.aspx
8/17/2015	8/20/2015	AV AFRANIO PEIXOTO, AV VALDEMAR FERREIRA, RUA HENRIQUE SCHAUMANN, AV PAULO VI, AV SUMARE, AV ANTARTICA, AV PROF MANUEL JOSE CHAVES, AV CARLOS CALDEIRA FILHO, AV VER JOSE DINIZ, ES DO CAMPO LIMPO	http://www.cetsp.com.br/noticias/2015/08/17/cet-implanta-reducao-de-velocidade-maxima-em-mais-11-vias-da-cidade.aspx
8/20/2015	8/23/2015	RUA DOMINGOS DE MORAIS, AV GUARAPIRANGA, ES M'BOI MIRIM, AV SEN TEOTONIO VILELA, AV ARNOLFO AZEVEDO, RUA ALM PEREIRA GUIMARAES, RUA DOMINGOS DE MORAIS	http://www.cetsp.com.br/noticias/2015/08/20/cet-implanta-reducao-de-velocidade-maxima-em-mais-6-vias-da-cidade-(1).aspx
8/24/2015	8/27/2015	AV PEDROSO DE MORAIS, AV PROF FONSECA RODRIGUES, AV DR GASTAO VIDIGAL	http://www.cetsp.com.br/noticias/2015/08/24/cet-implanta-reducao-de-velocidade-maxima-em-mais-3-vias-na-cidade.aspx
8/27/2015	8/31/2015	PTE ENG ARY TORRES, AV DOS BANDEIRANTES, AV AFFONSO D'ESCRAGNOLLE TAUNAY, CV MARIA MALUF, AV SANTOS DUMONT, AV TIRADENTES, AV PRESTES MAIA, TN PAPA JOAO PAULO II, AV VINTE E TRES DE MAIO, AV RUBEM BERTA, AV MOREIRA GUIMARAES, AV WASHINGTON LUIS, AV INTERLAGOS, AV WASHINGTON LUIS	http://www.cetsp.com.br/noticias/2015/08/27/cet-implanta-reducao-de-velocidade-maxima-em-mais-16-vias.aspx
9/3/2015	9/9/2015	AV SALIM FARAH MALUF, AV JUNTAS PROVISORIAS, RUA MALVINA FERRARA SAMARONE, AV PRES TANCREDO NEVES	http://www.cetsp.com.br/noticias/2015/09/03/cet-implanta-reducao-de-velocidade-maxima-em-mais-4-vias.aspx
9/4/2015	9/11/2015	AV FRANCISCO MATARAZZO, VD LESTE-OESTE, AV ALCANTARA MACHADO, RUA MELO FREIRE, AV CD DE FRONTIN, AV ANTONIO ESTEVAO DE CARVALHO, RUA DR LUIZ AYRES, RUA ENG SIDNEY APARECIDO DE MORAES, AV JOSE PINHEIRO BORGES	http://www.cetsp.com.br/noticias/2015/09/04/cet-implanta-reducao-de-velocidade-maxima-no-eixo-leste-oeste.aspx
9/14/2015	9/18/2015	RUA CARMOPOLIS DE MINAS, AV BANDEIRANTES DO SUL, RUA CEL GUILHERME ROCHA, RUA CIRO SOARES DE ALMEIDA, AV OLAVO FONTOURA, AV EDUC PAULO FREIRE	http://www.cetsp.com.br/noticias/2015/09/14/cet-implanta-reducao-de-velocidade-maxima-em-mais-7-vias.aspx
9/18/2015	9/23/2015	AV PEDRO ALVARES CABRAL, AV BRASIL, AV JABAQUARA, AV JABAQUARA	http://www.cetsp.com.br/noticias/2015/09/18/cet-implanta-reducao-de-velocidade-maxima-em-mais-5-vias.aspx
9/22/2015	9/25/2015	AV DO ESTADO, AV DO ESTADO, AV ATLANTICA	http://www.cetsp.com.br/noticias/2015/09/22/cet-implanta-reducao-de-velocidade-maxima-em-mais-2-vias.aspx
9/24/2015	9/30/2015	AV VITOR MANZINI, PTE DO SOCORRO	http://www.cetsp.com.br/noticias/2015/09/24/cet-implanta-reducao-de-velocidade-maxima-em-mais-3-vias.aspx
9/30/2015	10/2/2015	AV DOM PEDRO I, RUA TEREZA CRISTINA, AV NAZARE, AV DR RICARDO JAFET, AV DR RICARDO JAFET, AV PROF ABRAAO DE MORAIS	http://www.cetsp.com.br/noticias/2015/09/30/cet-implanta-reducao-de-velocidade-maxima-em-mais-5-vias.aspx
10/1/2015	10/7/2015	RUA MANUEL DA NOBREGA, AV REPUBLICA DO LIBANO, AV INDIANOPOLIS,	http://www.cetsp.com.br/noticias/2015/10/01/cet-implanta-reducao-de-velocidade-maxima-em-mais-3-vias.aspx
10/6/2015	10/9/2015	AV BRIG FARIA LIMA, RUA DOS PINHEIROS, AV HELIO PELEGRINO, RUA INHAMBU, TN SEBASTIAO CAMARGO, AV PRES JUSCELINO KUBITSCHEK, CV TRIBUNAL DE JUSTICA, RUA ANTONIO MOURA ANDRADE, CV AYRTON SENNA	http://www.cetsp.com.br/noticias/2015/10/06/cet-implanta-reducao-de-velocidade-maxima-em-mais-9-vias.aspx
10/9/2015	10/14/2015	AV PRES WILSON, RUA S RAIMUNDO, RUA S RAIMUNDO, RUA MANOEL PEREIRA DA SILVA, RUA MANOEL PEREIRA DA SILVA, AV DR FRANCISCO MESQUITA	http://www.cetsp.com.br/noticias/2015/10/09/cet-implanta-reducao-de-velocidade-maxima-em-mais-4-vias.aspx
10/14/2015	10/16/2015	AV REBOUCAS, AV EUSEBIO MATOSO, TN JORN FERNANDO VIEIRA DE MELO	http://www.cetsp.com.br/noticias/2015/10/14/cet-implanta-reducao-de-velocidade-maxima-em-mais-3-vias.aspx

Table A.2. 2015 Speed Limit Change Reports (Continuation)

Announcement Date	Speed Limit Change Date	Treated Roads	Link
10/16/2015	10/21/2015	AV PROF FRANCISCO MORATO, AV EMERICO RICHTER	http://www.cetsp.com.br/noticias/2015/10/16/cet-implanta-reducao-de-velocidade-maxima-em-mais-3-vias.aspx
10/20/2015	10/23/2015	AV DR ARNALDO, AV JORN ROBERTO MARINHO, PTE OCTAVIO FRIAS DE OLIVEIRA, AV JOAO SIMAO DE CASTRO	http://www.cetsp.com.br/noticias/2015/10/20/cet-implanta-reducao-de-velocidade-maxima-em-mais-3-vias.aspx
10/22/2015	10/28/2015	AV ROQUE PETRONI JUNIOR, AV PROF VICENTE RAO, AV VER JOAO DE LUCA, RUA JUAN DE LA CRUZ, AV CUPECE	http://www.cetsp.com.br/noticias/2015/10/22/cet-implanta-reducao-de-velocidade-maxima-em-mais-5-vias.aspx
10/26/2015	10/30/2015	AV DR HUGO BEOLCHI, AV ENG ARMANDO DE ARRUDA PEREIRA, AV ENG GEORGE CORBISIER	http://www.cetsp.com.br/noticias/2015/10/26/cet-implanta-reducao-de-velocidade-maxima-em-mais-3-vias-(1).aspx
10/29/2015	11/4/2015	AV CORIFEU DE AZEVEDO MARQUES, AV VITAL BRASIL, AV DOS TAJURAS, TN PRES JANIO QUADROS, AV LINEU DE PAULA MACHADO	http://www.cetsp.com.br/noticias/2015/10/29/cet-implanta-reducao-de-velocidade-maxima-em-mais-5-vias.aspx
11/4/2015	11/6/2015	PTE ENG ROBERTO ROSSI ZUCCOLO, AV CIDADE JARDIM, TN MAX FEFFER, AV EUROPA, RUA COLOMBIA, RUA AUGUSTA, RUA NOVE DE JULHO	http://www.cetsp.com.br/noticias/2015/11/04/cet-implanta-reducao-de-velocidade-maxima-em-mais-7-vias-(1).aspx
11/16/2015	11/19/2015	AV ELISEU DE ALMEIDA, RUA PIRAJUSSARA, AV INTERCONTINENTAL, AV JAGUARE, AV ESCOLA POLITECNICA, AV ESCOLA POLITECNICA, AV DR ANTONIO MARIA LAET, AV DR ANTONIO MARIA LAET, RUA PARANABI, RUA ARARITAGUABA, RUA ARARITAGUABA, AV DO POETA	http://www.cetsp.com.br/noticias/2015/11/16/cet-implanta-reducao-de-velocidade-maxima-em-mais-10-vias.aspx
11/19/2015	11/25/2015	AV S GABRIEL, AV SANTO AMARO, AV JOAO DIAS, AV ADOLFO PINHEIRO, RUA RHONE, AV ADUTORA DO RIO CLARO	http://www.cetsp.com.br/noticias/2015/11/19/cet-implanta-reducao-de-velocidade-maxima-em-mais-6-vias.aspx
11/23/2015	11/27/2015	AV MIGUEL IGNACIO CURI, RUA CASTELO DO PIAUI, AV RAGUEB CHOHFI, ES IGUATEMI	http://www.cetsp.com.br/noticias/2015/11/23/cet-implanta-reducao-de-velocidade-maxima-em-mais-5-vias.aspx
11/27/2015	12/2/2015	AV PAES DE BARROS, RUA TAQUARI, RUA BRESSER, VD BRESSER, AV BERNARDINO BRITO FONSECA DE CA, AV BERNARDINO BRITO FONSECA DE CA, AV PROF EDGAR SANTOS, AV PROF EDGAR SANTOS, AV ITAQUERA	http://www.cetsp.com.br/noticias/2015/11/27/cet-implanta-reducao-de-velocidade-maxima-em-mais-8-vias.aspx
12/2/2015	12/4/2015	AV PIRES DO RIO, AV DEP JOSE ARISTODEMO PINOTTI, AV DEP JOSE ARISTODEMO PINOTTI, ES DO IMPERADOR, ES DE MOGI DAS CRUZES, RUA EMBIRA, AV S MIGUEL	http://www.cetsp.com.br/noticias/2015/12/02/cet-implanta-reducao-de-velocidade-maxima-em-mais-6-vias.aspx
12/4/2015	12/9/2015	RUA DR ASSIS RIBEIRO, AV VER ABEL FERREIRA, RUA BRIG GAVIAO PEIXOTO, RUA MONTE PASCAL, VD DOMINGOS DE MORAES, AV GAL EDGAR FACO	http://www.cetsp.com.br/noticias/2015/12/04/cet-implanta-reducao-de-velocidade-maxima-em-mais-6-vias.aspx
12/9/2015	12/11/2015	AV INAJAR DE SOUZA, AV INAJAR DE SOUZA, AV COMEN MARTINELLI, AV ERMANO MARCHETTI, AV MARQ DE SAO VICENTE, RUA SERGIO TOMAS, RUA NORMA PIERUCCINI GIANNOTTI, AV RUDGE, VD ENG ORLANDO MURGEL, AV RIO BRANCO, AV ORDEM E PROGRESSO, PTE JULIO DE MESQUITA NETO, AV NICOLAS BOER, VD POMPEIA, AV ALEXANDRE COLARES, AV MANOEL MONTEIRO DE ARAUJO, AV DOMINGOS DE SOUZA MARQUES, AV ALM DELAMARE, RUA ANCHIETA, RUA FUNCHAL, AV CHEDID JAFET	http://www.cetsp.com.br/noticias/2015/12/09/cet-implanta-reducao-de-velocidade-maxima-em-mais-24-vias.aspx
12/14/2015	12/16/2015	AV SARG MIGUEL DE SOUSA FILHO, AV TTE AMARO FELICISSIMO DA SILVEIRA, AV TTE AMARO FELICISSIMO DA SILVEIRA, AV SERAFIM GONCALVES PEREIRA, AV MORUMBI	http://www.cetsp.com.br/noticias/2015/12/14/cet-implanta-reducao-de-velocidade-maxima-em-mais-4-vias.aspx
12/16/2015	12/18/2015	RUA MANOEL BARBOSA, AV RAIMUNDO PEREIRA DE MAGAL., RUA PRINCIPAL(PERUS), RUA GUIDO CALOI, AV GIOVANNI GRONCHI, ES DO ALVARENGA, RUA DR JOSE MARIA WHITAKER, RUA ALVINOPOLIS, AV ANTONIO BATUIRA, AV QUEIROZ FILHO, RUA CERRO CORA, RUA CERRO CORA, RUA CERRO CORA, RUA CONS MOREIRA DE BARROS, RUA MAUA	http://www.cetsp.com.br/noticias/2015/12/16/cet-implanta-reducao-de-velocidade-maxima-em-mais-14-vias.aspx
12/16/2015	12/18/2015	AV DUQ DE CAXIAS	http://capital.sp.gov.br/noticia/cet-implanta-reducao-de-velocidade-maxima-em-mais-14-vias
12/30/2015	12/29/2015	AV LUIZ GUSHIKEN	http://www.cetsp.com.br/noticias/2015/12/30/cet-implanta-reducao-de-velocidade-na-avenida-luiz-gushiken.aspx

Figure A.1. Traffic Agency Report of an Upcoming Speed Limit Reduction (2015)

» Emergências no Trânsito: Ligue 1188

Companhia de Engenharia de Tráfego

Página Inicial | Perguntas Frequentes | Mapa do Site | Acesso à Informação | Participação Social |

PREFEITURA DE SÃO PAULO MOBILIDADE E TRANSPORTES

CET » Notícias »
Programa de Proteção à Vida - CET implanta redução de velocidade na Avenida Aricanduva

A- | A+

Notícias

30/07/2015 02:43

Por: CET

Programa de Proteção à Vida - CET implanta redução de velocidade na Avenida Aricanduva

A ação visa aumentar a segurança para usuários e incentivar o melhor compartilhamento do espaço urbano

A Companhia de Engenharia de Tráfego implantará a partir desta segunda-feira (03/08) redução de velocidade na Avenida Aricanduva e no Elevado Engenheiro Alberto Badra, na Zona Leste, onde será regulamentada a velocidade máxima de 50 km/h. Atualmente, a velocidade permitida é de 60 km/h. A medida está inserida no plano de redução de acidentes viários do "Programa de Proteção à Vida". Com isso, pretende-se melhorar a segurança dos usuários mais vulneráveis do sistema viário, pedestres e ciclistas, buscando a convivência pacífica e a redução de acidentes e atropelamentos na área.

Alterações no Sistema Viário

· Regulamentação de velocidade máxima de 50 km/h na Avenida Aricanduva e no Elevado Engenheiro Alberto Badra, em ambos os sentidos, toda extensão (13,4 km), conforme folha informativa anexa.

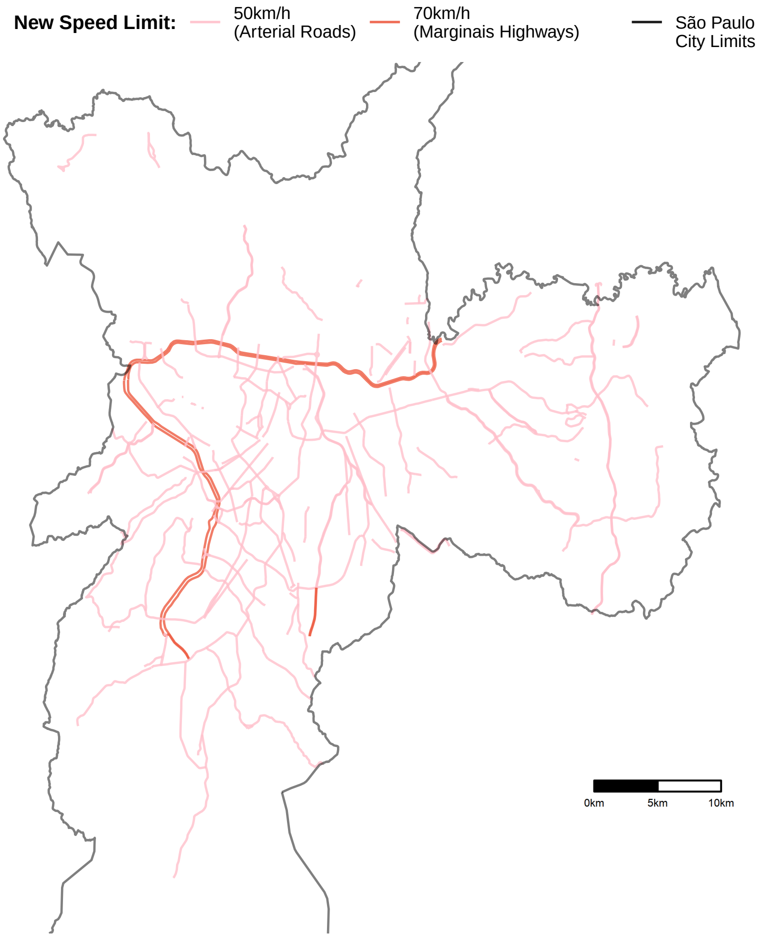
A medida se faz necessária vista que a referida via possui tráfego intenso e grande volume de pedestres. Na Avenida Aricanduva, entre janeiro de 2011 e dezembro de 2014, aconteceram 828 acidentes veiculares com vítimas e 132 atropelamentos, resultando em 1286 pessoas feridas e 45 mortes. Desta forma, velocidades menores são necessárias para promover condições seguras e confortáveis de circulação aos pedestres que ainda representam o maior número de vítimas no trânsito em São Paulo.

Para implantação da redução de velocidade na Avenida Jacu-Pêssego serão utilizadas 246 novas placas de sinalização vertical de regulamentação e advertência, além de nove faixas de vinil e 10 banners nos principais acessos, alertando os motoristas quanto à mudança.

A Engenharia de Campo da CET vai acompanhar o desempenho da nova medida e orientar o tráfego na região.

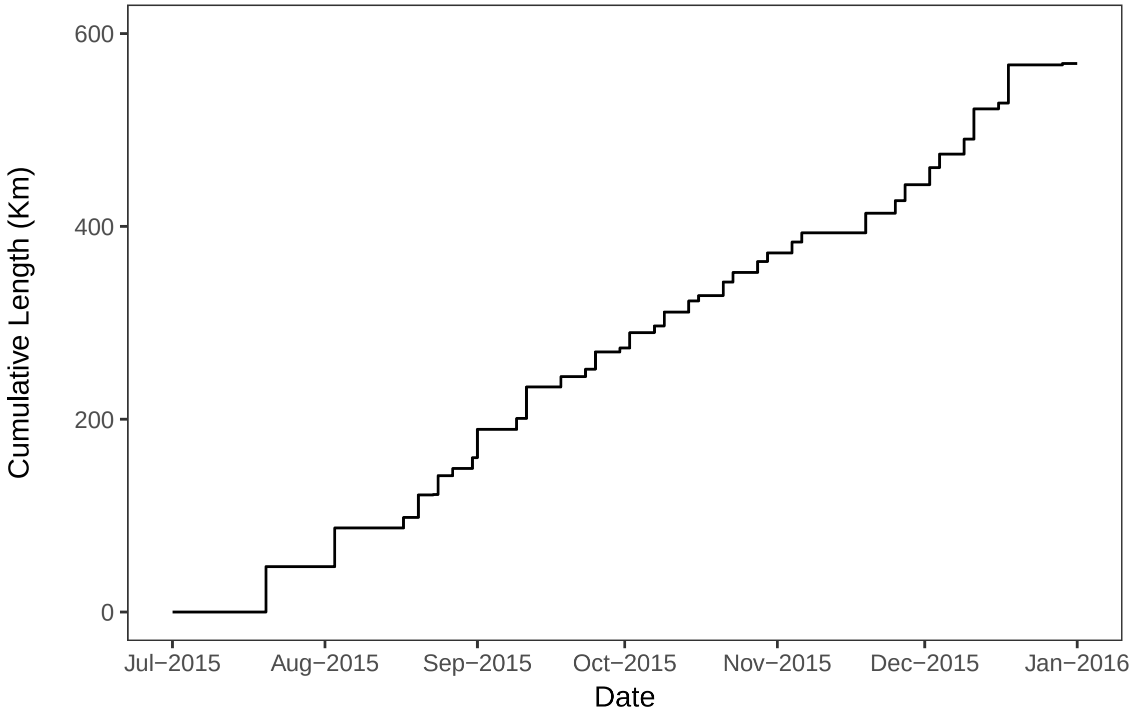
Fale com a CET - Ligue 1188. Atende 24 horas para informações de trânsito, ocorrências, reclamações, remoções e sugestões.

Figure A.2. Road Segments with Speed Limit Reductions by New Speed Limit



Notes: Information about speed limit changes was scraped from the newsletters of the São Paulo Transit Agency Website (http://www.cetsp.com.br/noticias.aspx). Appendix A provides additional details about this dataset.

Figure A.3. Cumulative Length of Road Segments with Speed Limit Reductions



Notes: Information about speed limit changes was scraped from the newsletters of the São Paulo Transit Agency Website (http://www.cetsp.com.br/noticias.aspx). Appendix A provides additional details about this dataset.

A.2 Characteristics of Motorized Trips and Travelers

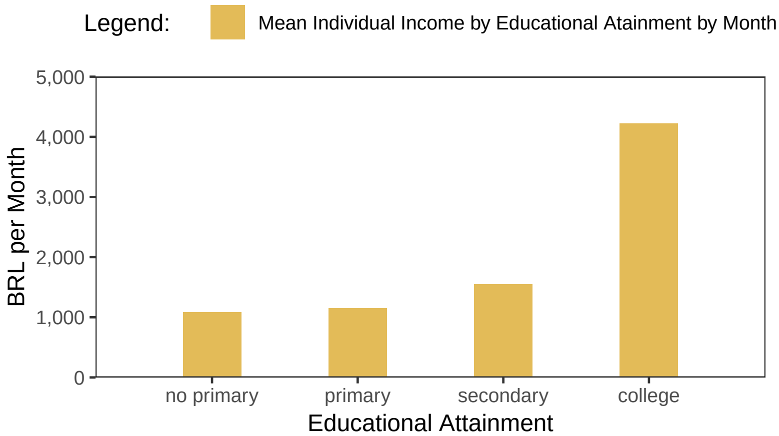
Table A.3 presents basic descriptive statistics of motorized trips made on a regular weekday in São Paulo Brazil. The table was constructed using trip data from the Mobility Household Survey of 2012, which we used as the source of representative trips for our web-crawler.[54] We also used the data from the household travel survey to plot the relationship between the educational attainment of individuals and their income, which is shown in Figure A.4 below. As expected, the relationship is very clear, with larger average income for individuals with higher educational attainment.

Table A.3. Characteristics of Motorized Trips in a Weekday in São Paulo

	Trips per Day (Million)	Share	Mean Distance (km)	Mean Duration (minutes)
Motorized trips	29.74	1.00	7.99	50.53
By mode				
Bus	11.78	0.40	6.83	58.73
Rail	4.36	0.15	16.61	88.56
Car	12.49	0.42	6.02	31.46
Motorcycle	1.04	0.03	8.50	27.86
By motivation				
Work	16.81	0.57	9.88	60.25
Education	7.51	0.25	4.73	35.72
Other	5.43	0.18	6.90	43.14

Notes: This table was created by the authors based on data from the 2012 Mobility Household Survey of São Paulo (Pesquisa de Mobilidade Urbana 2012)

Figure A.4. Average Individual Income by Educational Attainment



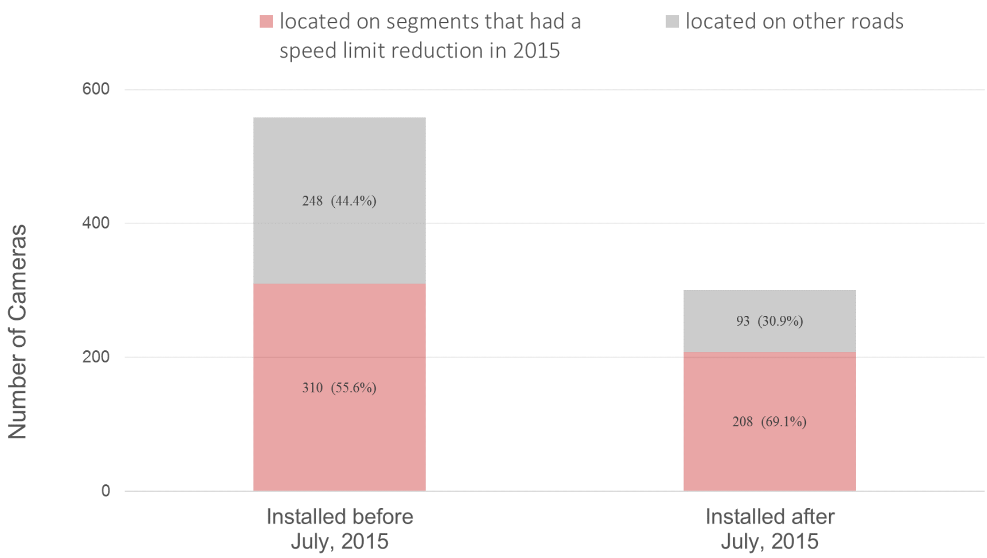
Notes: Based on the sample of adult individuals from the 2012 São Paulo Household Travel Survey.

[54]Further details about the survey can be found at http://www.metro.sp.gov.br/pesquisa-od/resultado-das-pesquisas.aspx

A.3 Location of cameras installed in 2015

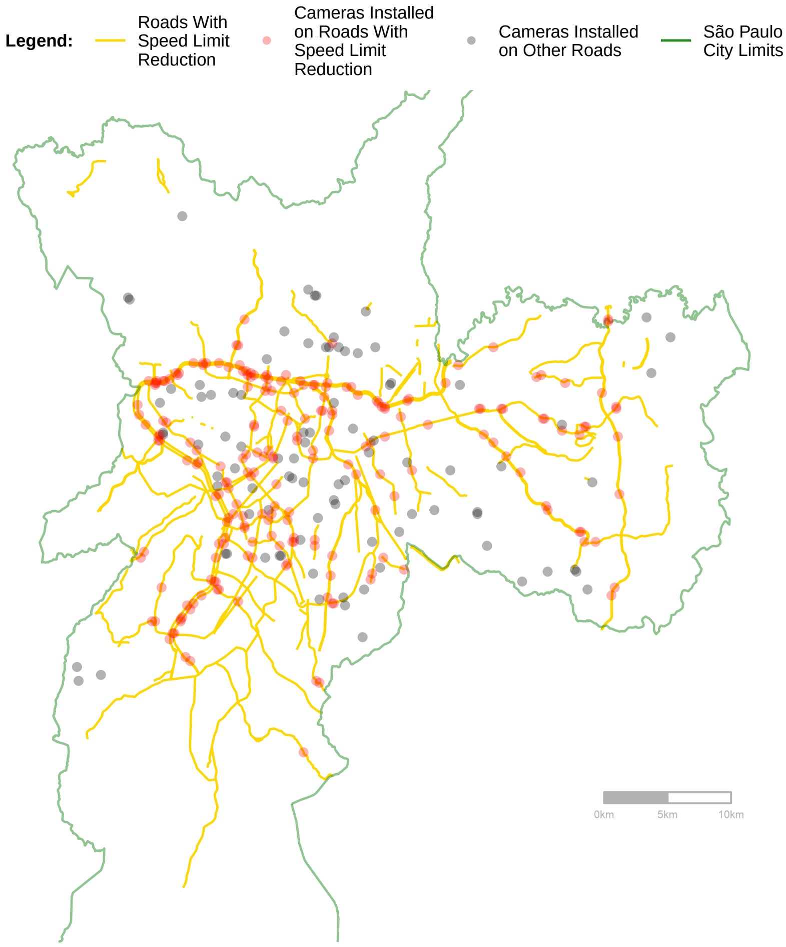
Throughout 2015, there was a substantial expansion of the number of traffic speeding monitoring cameras in São Paulo. However, the installation of these new cameras was not random with respect to location. More speed cameras were installed on road segments where speed limits were reduced. Figure A.5 shows the location of cameras installed before and after July 20, 2015 (the first speed limit change). 55.6% of the cameras installed before July 20, 2015 were installed on segments that were treated with speed limit reductions. That ratio increased to 69.1% as a result of installations occurring after that date. Figure A.6 maps the location of the later group of cameras, clearly illustrating the concentration of new cameras on treated road segments, particularly the Marginais Highways.

Figure A.5. Speed Control Cameras in São Paulo by Date of Installation and Treatment Group



Notes: Information about cameras and their location was extracted from the website http://mobilidadesegura.prefeitura.sp.gov.br/ which is maintained by the São Paulo City Hall and compiles information about traffic violations in the city. Road segments are defined as "Treatment Group" if their speed limit was reduced in 2015 and "Other Roads" if the segment's speed was not altered in that year.

Figure A.6. Segments with Contemporaneous Speed Limit Reductions and Camera Installation

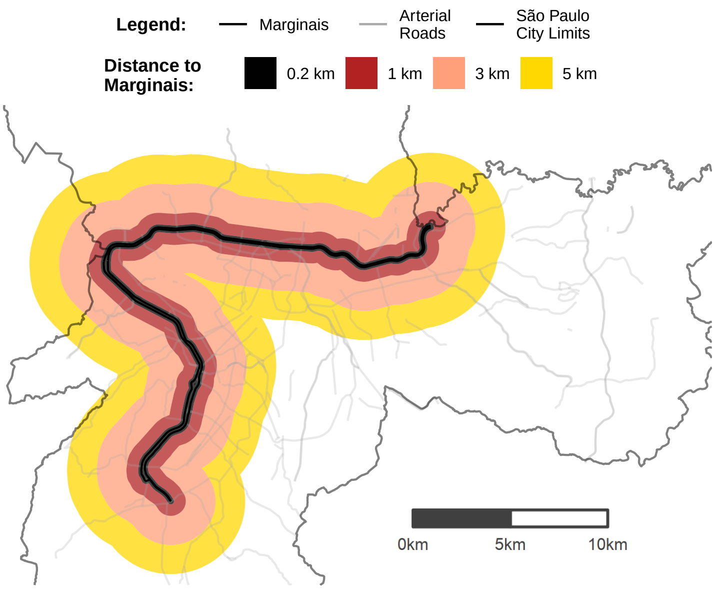


Notes: We identify the date a camera was installed using the minimum date for speeding tickets issued in each location. Data about traffic tickets was scraped from the website Painel de Mobilidade Segura (http://mobilidadesegura.prefeitura.sp.gov.br), which is maintained by the São Paulo Transit Agency (CET).

A.4 Spillover Areas of the Travel Time Empirical Model

Figure A.7 maps the road areas which we identified as possible spillover areas for the effects of the speed limit increase in the Marginiais Highways on Travel Time. The areas were constructed using non-overlaping buffers from the Marginais Highways shapefile.

Figure A.7. Marginais Highways: Treated and Spillover Zones

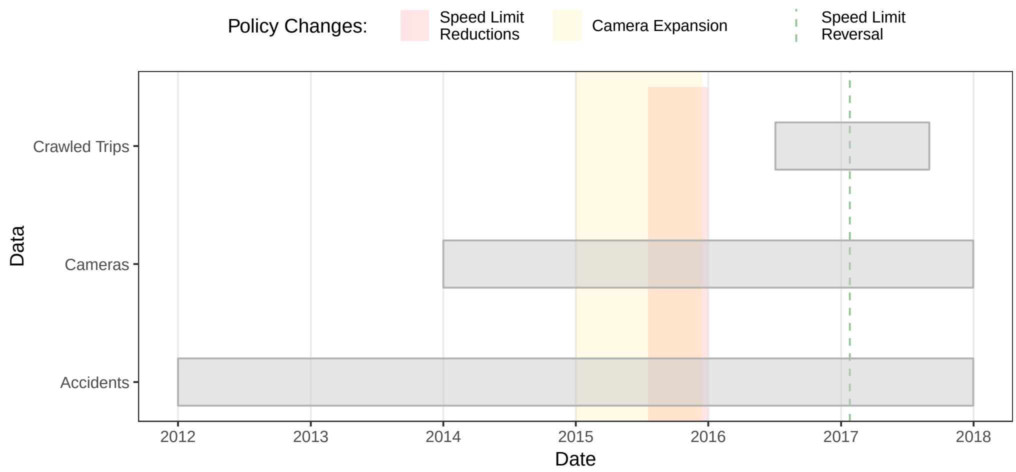


Notes: Buffers were constructed using the shapefile of the Marginais highways.

A.5 Timeline of Policy Changes and Data

Figure A.8 summarizes the timeline of policy changes and the temporal overlap of datasets included in our analysis. For the 2017 speed limit reversal, we have information about accidents, traffic cameras and crawled trips from both before and after the policy change date. However, in the case of the speed limit reductions of 2015, we do not have information about estimated travel times from before the policy because trip queries began in mid-2016. The dataset of road accidents begins in 2012, allowing us to evaluate secular trends in road accidents for both the treatment and control groups.

Figure A.8. Timeline of Speed Limit Changes and Datasets

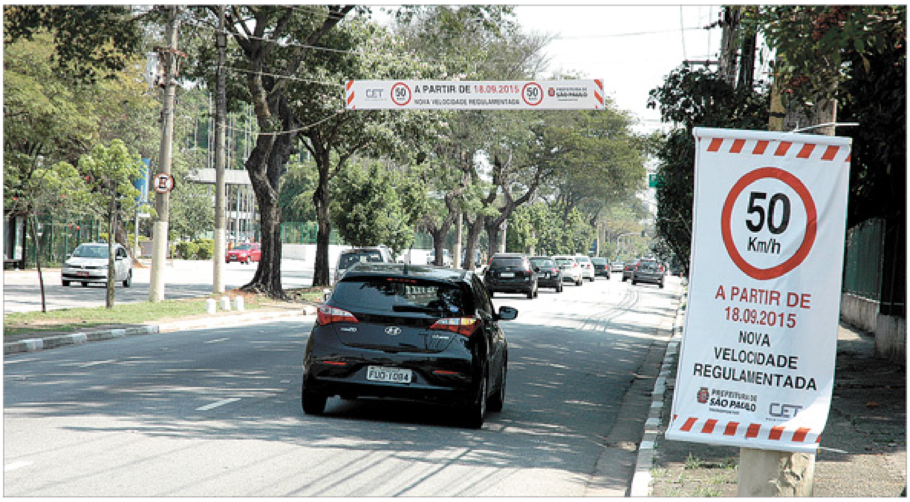


Notes: Crawled Trips refer to representative trips observed on a household travel survey and that were repeatedly simulated using Google Direction's API. Data about speed monitoring cameras was scraped from the website Painel de Mobilidade Segura (http://mobilidadesegura.prefeitura.sp.gov.br), which is maintained by the São Paulo Transit Agency (CET). The datasets of road accidents were obtained by the authors through a series of LAI (Lei de Acesso à Informacão) requests.

B Signs Announcing Upcoming Speed Changes

Before new speed limits were implemented, the Traffic Agency of São Paulo would place banners and signs indicating the upcoming change. Figure B.1 shows an example of these signs. These banners would inform drivers about the new speed limits and the dates when the they would become effective. Unfortunately, the Traffic Agency did not retain records of the exact dates when these banners and signs were placed on each road segment. However, because the signs closely resemble actual speed limit signs, we believe that they could cause drivers to start driving more slowly even before the actual date of speed limit change in each segment. In our robustness analyses, we do find evidence of a reduction in accidents on treated segments in the quarter immediately before treatment. Therefore, to avoid any bias in our main results, our baseline specification excludes observations from the quarter immediately before the speed limit reduction in each road segment.

Figure B.1. Banners Indicating an Upcoming Speed Limit Reduction (2015)



C Accident Costs Parameters

We calculate the monetary cost of accidents in our database by matching the characteristics of individual accidents to cost parameters estimated in the literature. In the case of non-fatal accidents we use the parameters estimated by IPEA (2016), a report from the Brazilian Institute of Applied Economics, which includes estimates of the cost of road accidents in Brazil. The report estimates specific parameters based on the type of vehicle and the severity of accidents. The latter is measured in terms of the severity of injuries faced by the victims of accidents. We include these estimates in our cost-benefit analysis to account for heterogeneity in vehicle type and injury severity in our accident data. For example, we calculate that the vehicle cost for a motorcycle accident where the driver was injured is R$ 2,741. For this same accident, the cost of victim injuries is R$ 66,802.

For fatal accidents, we use the Value of Statistical Life (VSL) calculated by Viscusi and Masterman (2017) for Brazil. In this paper, the authors explore the richness of data available for the USA and differences in income between countries to calculate VSL for countries with limited information.

Table C.1. Accident Costs by Type

	Accident Severity		
	No Injuries	With Injuries	With Fatalities
Vehicle Costs			
Auto	7,159	12,127	19,324
Motorcycle	2,473	2,741	4,270
Bike	0	169	124
Utility Veh.	10,570	20,240	35,091
Truck	22,314	65,656	47,825
Bus	16,069	10,537	20,686
Other	10,307	80,109	81,209
Victims Cost			
Unharmed	1,086	4,111	1,840
Injured	-	66,802	74,896
Fatality	-	-	3,862,030

Notes: All values are presented in BRL of 2015. Most parameters were extracted from IPEA (2016), except Fatal Victims Costs, for which the parameter is taken from from Viscusi and Masterman (2017).

D Comparison of Results with the Literature

To the extent of our knowledge, there exists no other study that estimates the reduced-form effects of speed limits in a developing country city and estimates costs and benefits using a welfare framework. The study that most closely approximates our research design is van Benthem (2015), (henceforth VB). Both papers conduct a comprehensive ex-post evaluation of impacts from speed limit changes in the sense that they capture the primary benefits and costs from the policy, which increases the value of a comparison of primary results. However, there are important differences with respect to the setting evaluated in the papers. VB examines speed limit changes from more than 20 years ago on regional freeways in Western USA,[55], whereas our study examines a policy change from 2015 on urban roads in a metropolitan area of the developing world. When comparing the results from both papers, it is important to acknowledge that each of these dimensions may contribute to differences in estimates.

Table D.1 summarizes the comparable results between the two studies.[56][57] We note that the VSL and VOT parameters used in our study were both about 20% of the main parameters used by VB, which facilitates the comparison of results in very different economic settings, but that have a comparable VSL/VOT ratio.

With respect to reduced form policy impacts, we find highly consistent estimates of the effect of speed limit changes on travel time, with an average effect of approximately 6% in the same direction as the limit change. This is interesting and even somewhat surprising given the differences in measurement and the transport systems. The primary difference in the results presented between the two studies concerns impacts on accidents. While the present study documents a reduction of 40% on the Marginais Highways, VB identified an average effect of 14% on American highways (he found an effect of 44% in the case of fatalities). In our study, we were not able to isolate the effect of the policy on fatal accidents with sufficient precision since they are observed with less frequency. Therefore, we assume that the effect on fatalities was proportional to the policy effect on total accidents (40%). In both studies, if travel time costs are computed using the VTPI VOT, the breakeven VSL approaches zero as the changes in non-fatal accidents alone compensate the losses in travel time.

Perhaps the most important conclusion regarding the comparison of two studies in very different settings is the clear and consistent conclusion regarding the social benefits of speed limits. In both studies, the benefits related to fewer accidents were found to be substantially larger than the costs of extended commuting times, which lends some confidence to the external validity of both the empirical estimates and the broader conclusions. While in the VB study the central estimate of the benefit/cost ratio was 2.21, the comparable ratio in São Paulo was 2.13. However, the relative breakeven VSL in VB

[55]The roads evaluated in VB were located in the states of California, Oregon and Washington.

[56]VB evaluated the effects of a speed limit increase, whereas the present paper evaluates a speed limit reduction. Therefore, to align the direction of results and increase comparability, we invert his labels of costs and benefits, so we use "costs" to refer to the value of additional travel time, and "benefits" to refer to reductions in accidents.

[57]In addition to the sources of costs and benefits studied in this paper, van Benthem (2015) estimates the effects of speed limit changes on air pollution and its consequent impacts on health. While these effects are estimated to approximately double the social costs of speed limit increases, they are admittedly uncertain according to the author. Our work on the estimation of policy effects on pollution is ongoing. Therefore, when comparing the results between the papers, we exclude VB results associated with pollution and health impacts and compare the effects on road accidents and travel time only.

was about 4 times smaller than in our study. Multiple factors contribute to this difference as the setting in both studies differ in several dimensions such as average travel speed, accidents and fatalities ratios, but primarily, we have a much larger policy effect on non-fatal accidents in São Paulo (-40% compared to -14%). Because of that, the portion of benefits that does not depend on VSL is nearly large enough to fully offset the costs of longer trips.

Table D.1. Comparison of Findings with van Benthem (2015)

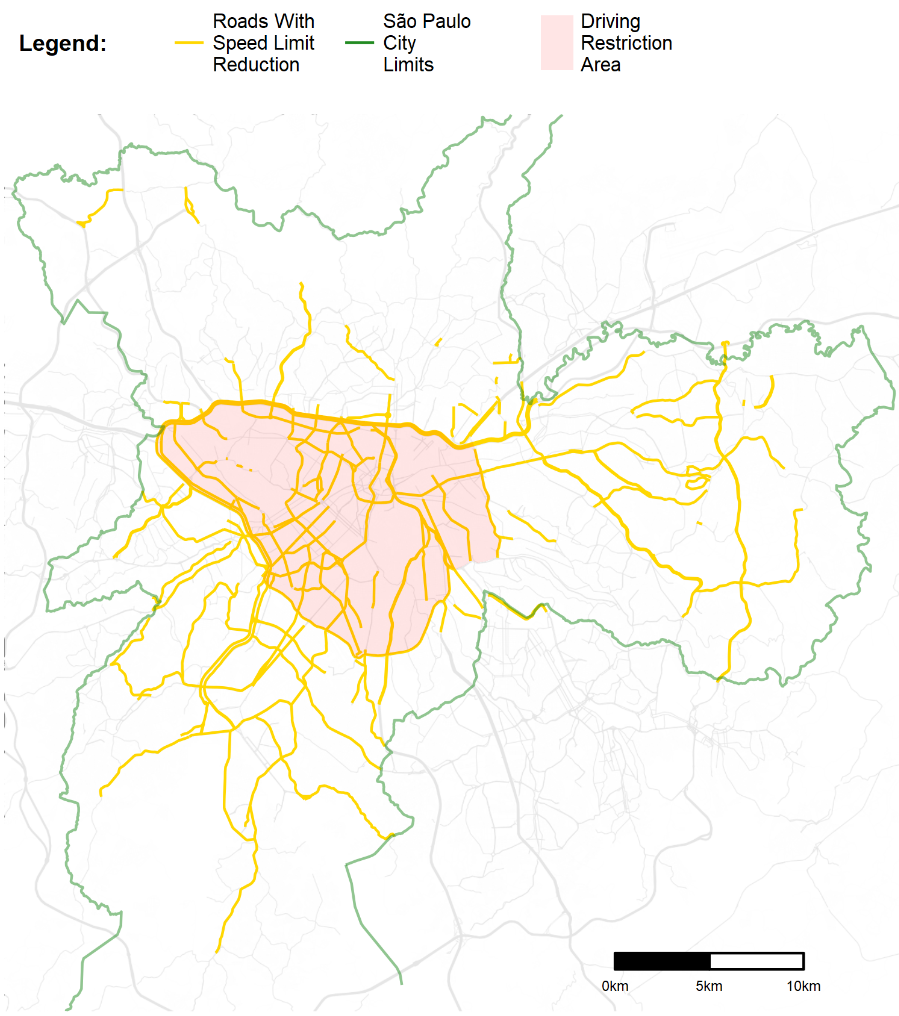
	Ang, Christensen & Vieira (2018) *Urban highways in São Paulo, Brazil*	Van Benthem (2015) *Western USA freeways*	Ratio *ACV/VB*
Cost-benefit results			
Benefits/costs	2.13	2.21	0.96
Breakeven VSL ratio[a]	0.19	0.50	0.38
Main parameters			
VSL *(U$ million)*	1.72	8.78	0.20
VOT *(U$ per hour)*	3.89	18.31	0.21
Pre-treatment values			
Average vehicle speed *(km/h)*	35.45	96.80	0.37
VKT per year *(billion)*	2.22	4.63	0.48
VHT per year *(million)*	62.60	47.80	1.31
Accidents per year	801	1010	0.79
Fatalities per year	41	24	1.71
Accidents per million VHT	12.8	21.1	0.61
Fatalities per million VHT	0.65	0.50	1.30
Reduced form estimates			
Travel time	0.057	0.059	0.97
Accidents	0.40	0.14	2.86
Fatalities	0.40	0.44	0.91

Notes: All monetary values are in USD of 2016. [a] Breakeven VSL divided by baseline parameter.

E São Paulo Driving Restriction

The city of São Paulo enforces a driving restriction scheme that limits the circulation of 20% of vehicles during peak-hours in the central area of the city. The restriction is based on the final digit of a vehicle's license plate. All Brazilian license plates have a number as their final digit, so the driving restriction of São Paulo limits the circulation of vehicles with license plates ending in 2 different numbers. For example, on Mondays, vehicle license plate numbers with final digits 1 and 2 are not allowed to circulate in the São Paulo Downtown Area. Figure D.1 shows the Driving Restriction Area of São Paulo and its overlap with the streets which had their speed limit altered in the period of our analysis.

Figure D.1. Road Segments with Speed Limit Reductions and the Driving Restriction



F Alternative Specification of Empirical Models

In this Appendix, we verify the sensitivity and robustness of our empirical results. We estimate the policy treatment effect using alternative model specifications and compare their results with the preferred specification reported in the paper.

F.1 Robustness of Accident Results to Alternative Model Specifications

We estimate two alternative versions of our main model: (1) A specification that does not discard observations from the quarter immediately before the policy adoption in each segment; (2) We estimate a linear version of the main empirical model. In the latter case, to estimate coefficients directly as a relative change ratio and compare those results directly with our baseline model, we transform the dependent variable by dividing each value by the average number of accident per segment and estimate the following model:

$$\frac{y_{it}}{\bar{y_i}} = \alpha_i + \beta_t + \left(\sum_{q=1}^{7^+} \gamma_q \cdot D_{it}\right) + \zeta \cdot C_{it} + \eta \cdot C_{it} \cdot SLR_{it} + \phi SLI_{it} + \varepsilon_{it} \tag{6}$$

Where $\bar{y_i}$ is the average number of accidents per month on segment i during the baseline period and everything else is equal to equation 1.

Table F.1 compares the long term policy effect estimates between the baseline Poisson model used in our main text and the two alternative specifications described above. Results are consistent across all models and are not statistically different from each other, thus indicating the robustness of our main results to these alternative specifications.

Table F.1. Long-Term Policy Effect Using Alternative Model Specifications

	Dependent variable: number of accidents per segment per month				
	Sample of segments:				
	(1)	(2)	(3)	(4)	(5)
Long Term Speed Limit Reduction Effect					
Baseline Poisson Model	-0.186 ***	-0.279 ***	-0.312 ***	-0.289 ***	-0.380 ***
	(0.026)	(0.032)	(0.042)	(0.032)	(0.034)
Alternative Poisson Model	-0.183 ***	-0.272 ***	-0.305 ***	-0.283 ***	-0.312 ***
(keeping pre-treatment 1st quarter)	-0.026	-0.031	-0.041	-0.031	-0.034
Linear Model	-0.142 **	-0.248 ***	-0.272 ***	-0.322 ***	-0.365 ***
	(0.044)	(0.055)	(0.067)	(0.045)	(0.088)
Treatment group	All treated arterial and highways	All treated arterial and highways	Treated arterial and highways w/ >11 accidents2	Matched arterial and highways	All treated arterial and highways
Control group	All non-treated avenues	Non-treated ave. >1.6km away from treatment	Non-treated ave. >1.6km away from treatment, >11 accidents	Non-treated ave., >1.6km away from treatment, matched to treatment segm.	None
Segment FE	Yes	Yes	Yes	Yes	Yes
Year-month FE	Yes	Yes	Yes	Yes	No
Parametric funct. form	No	No	No	No	Yes

Notes: For the Poisson model, coefficients are reported as relative incidence ratios. In the case of the linear model, the dependent variable was pre-multiplied by the inverse of mean accidents per segment in the pre-period. Therefore, in both cases, coefficients reported can be interpreted as relative incidence ratios. For instance, a coefficient of 0.1 indicates a 10% larger incidence of accidents. All specifications were estimated using a monthly panel of road segments, however specifications differ w.r.t. the observations that were included in each regression. Specifications (1)-(4) use different sets of treated highways and arterial roads, and non-treated avenues. Specification (5) only include treated segments. Specifications (1)-(4) include monthly fixed effects, and specification (5) uses a parametric functional form that includes a linear time trend and two citywide covariates (fuel sales and total number of cameras).

F.2 Robustness of Travel Time Results to Sample Subset

This section evaluates the robustness of our main travel time results to the inclusion of queries made 2 hours before or after the time that representative trips were originally made. In our baseline estimation, we included all API queries irrespective of whether they matched precisely the original departure time in the survey. Therefore, we compare our baseline estimates to an alternative regression where we subset our crawled trips observations to queries made at the exact time of the day when trips were made. The purpose of this exercise is to test whether the inclusion of those queries made on the interval around actual departure could lead to a significant bias in our results.

Table F.2 presents the main policy effect estimates from both models. The differences between results are not statistically or economically different across models.

Table F.2. Effect of Speed Limit Increase on Trip Durations: Exact Trips

	Changes in Estimated Travel Time			
	(1)	(2)	(3)	(4)
Baseline Results				
Policy Effect - pooled	-0.065 ***	-0.058 ***	-0.057 ***	
	(0.014)	(0.013)	(0.013)	
Policy Effect - peak hours				-0.027
				(0.025)
Policy Effect - offpeak				-0.075 ***
				(0.011)
Subset of queries made true departure time				
Policy Effect - pooled	-0.069 ***	-0.062 ***	-0.061 ***	
	(0.015)	(0.015)	(0.015)	
Policy Effect - peak hours				-0.024
				(0.025)
Policy Effect - offpeak				-0.087 ***
				(0.013)
Trip-Hour FE	Yes	Yes	Yes	Yes
Month FE	No	No	Yes	Yes

Notes: Coefficients indicate the average changes of dependent variables with respect to pre-treatment means. For example, a coefficient of -0.5 indicates a reduction of 50%. Standard Errors are clustered by date Street (191 clusters). Post SLI is a dummy that indicates queries made after the speed limit increase on the Marg. in January 25, 2017. Rain is a dummy indicating if there was positive registers of rain during the hour of each query was made. Trip-Hour Fixed effects include a specific intercept for each pair of origin and destination coordinates queried in a certain hour of the day.

G Behavioral Spillovers: Accident Reductions and Ticketing on Nearby Roads

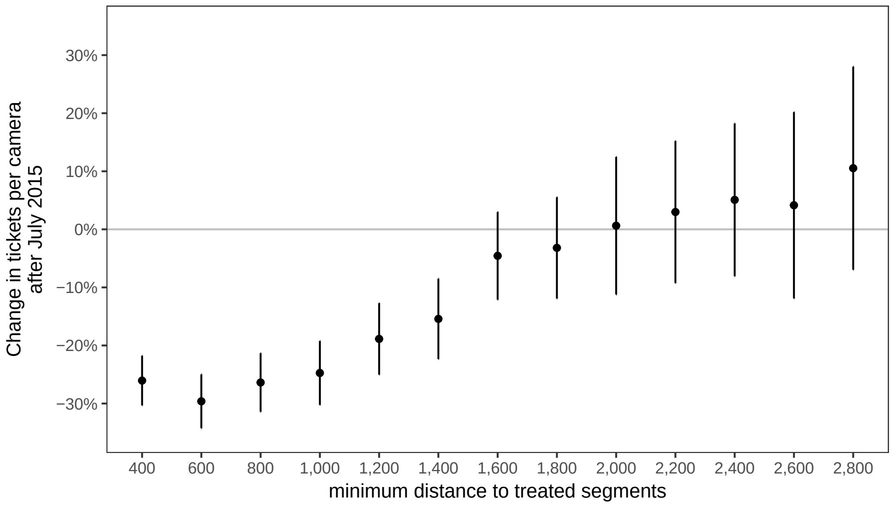
To evaluate possible changes in driver behavior on non-treated segments, we evaluate changes in the number of speeding tickets on cameras issued on segments that were nearby treated roads but were not treated. Given that most trips utilize a combination of treated and never-treated road segments, it is likely that any change in driver behavior induced by the policy also affects the untreated portion of a trip. While the speed change was fairly well advertised on treated roads, it could also be the case that drivers were not aware of the extent of the change and altered their behavior more generally. We use the following regression specification to evaluate behavioral spillovers:

$$y_{it} = \alpha_i + \beta \cdot SLR_t + \varepsilon_{it} \tag{7}$$

Where y_{it} is the log of the number of tickets issued by camera i during month t, and SLR_t is an indicator of panel observations from the period after July 2015 when the first speed limit reduction was adopted. Therefore, β indicates the average change in the number of tickets issued by cameras located on never-treated segments. To evaluate the geography of behavioral spillovers, we estimate this model using different definitions of never-treated segments based on their distance to treated road. We start by defining non-treated observations as any road segments located more than 400m away from treated roads, and we increase that threshold gradually, 200m at a time.

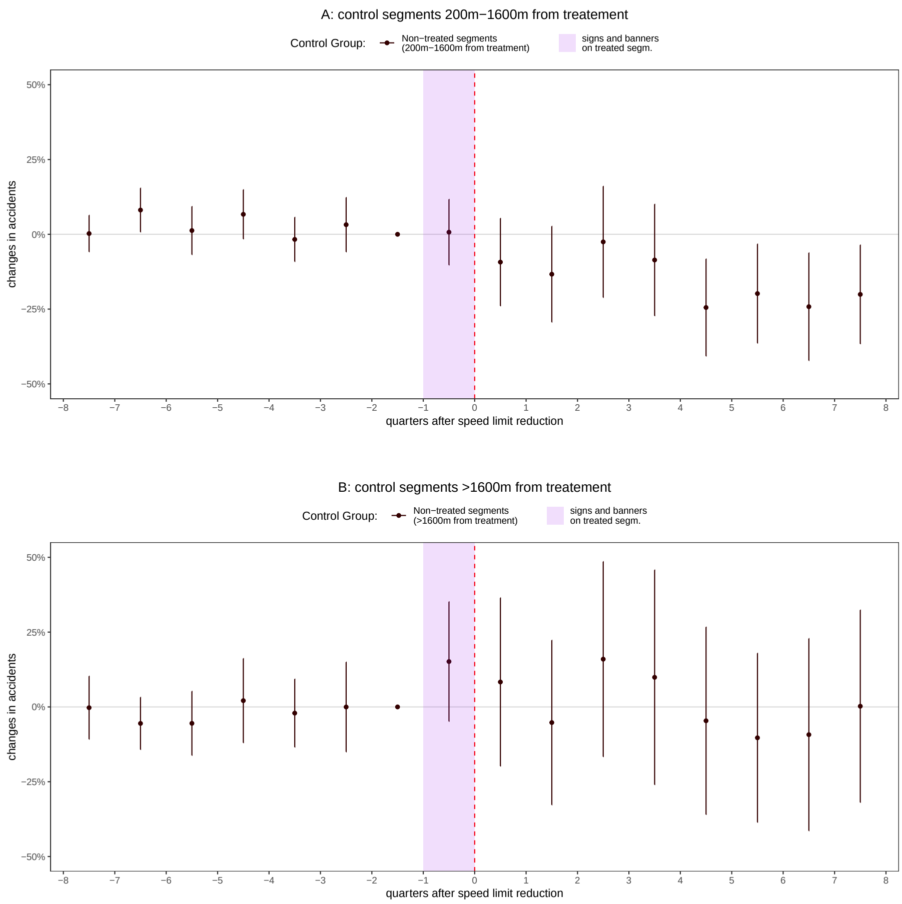
We plot the estimate of β for each of these distance thresholds in Figure G.1. At larger distance thresholds, the estimates become less precise as the sample of cameras on never-treated segments is reduced. The estimates suggest a clear pattern of reductions in speeding tickets on non-treated roads nearby treated segments. The decline in tickets is statistically significant up to 1,600 meters from treated roads. This exercise provides evidence to suggest that drivers adjust their behavior not only on treated road segments, but also on the roads near treated areas.

Figure G.1. Changes in Speeding Tickets on Nearby Control Segments



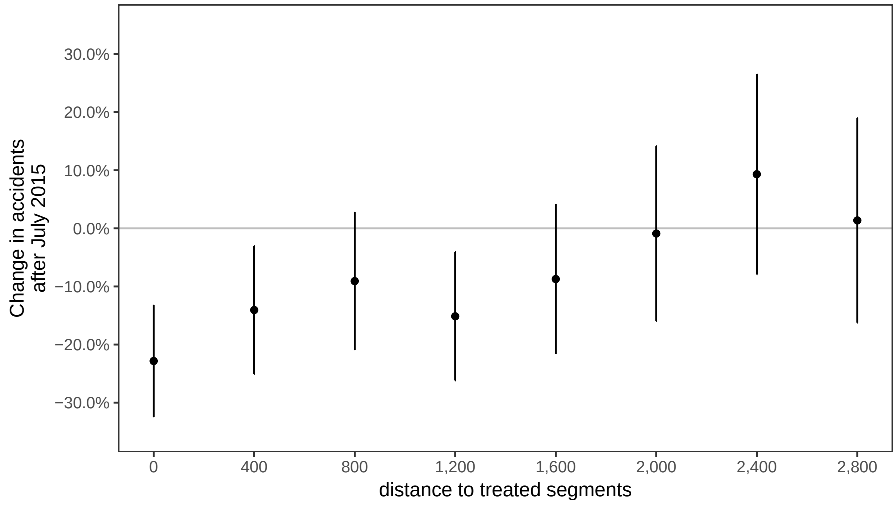
Next, we evaluate actual changes in accidents on never-treated segments. We estimate an event study model that mirrors our specification based on sample (5) in the main text, substituting two sets of never-treated segments for our treatment group in the model. Figure G.2 plots the result coefficients for each of these groups. Panel A plots the changes in road accidents by relative quarter for non-treated segments located within 1600 meters of treated roads. This is the zone where behavioral spillovers are identified in Figure G.1. Panel B plots the same estimates using never-treated segments that are located beyond 1,600 meters from treated roads. In both cases, the coefficients associated with the periods preceding the policy change are not statistically different from zero. However, the estimates in Panel A indicate that there was a modest reduction in road accidents on nearby treated segments that was statistically different from what would be expected from secular trends in the period following the speed limit reduction. The same result is not observed in panel B.

Figure G.2. Changes in Accidents on Nearby Control Segments



A final test extends our main regression model to explicitly estimate the longer-term changes in road accidents on non-treated segments according to their distance to treated roads. Never-treated segments are classified according to gradually increasing rings of 400m each around treated roads and we interact the post-treatment period with an indicator for segments located in each of these rings. Figure G.3 plots the estimates as a function of distance to treated segments. The leftmost coefficient (X=0) is the longer-term change in road accidents on treated road segments compared to changes observed on segments located more than 2,800 meters away from any treated road. The next coefficient illustrates the change in road accidents on non-treated segments located between 0-400 meters of treated roads, and so forth. The results suggest reductions in road accidents on never-treated segments located within 1,600 meters of treated roads. This reduction diminishes as distance to the treated roads increases.

Figure G.3. Regression Results: Long Term Changes in Accidents on Control Segments by Distance to Treated Segments



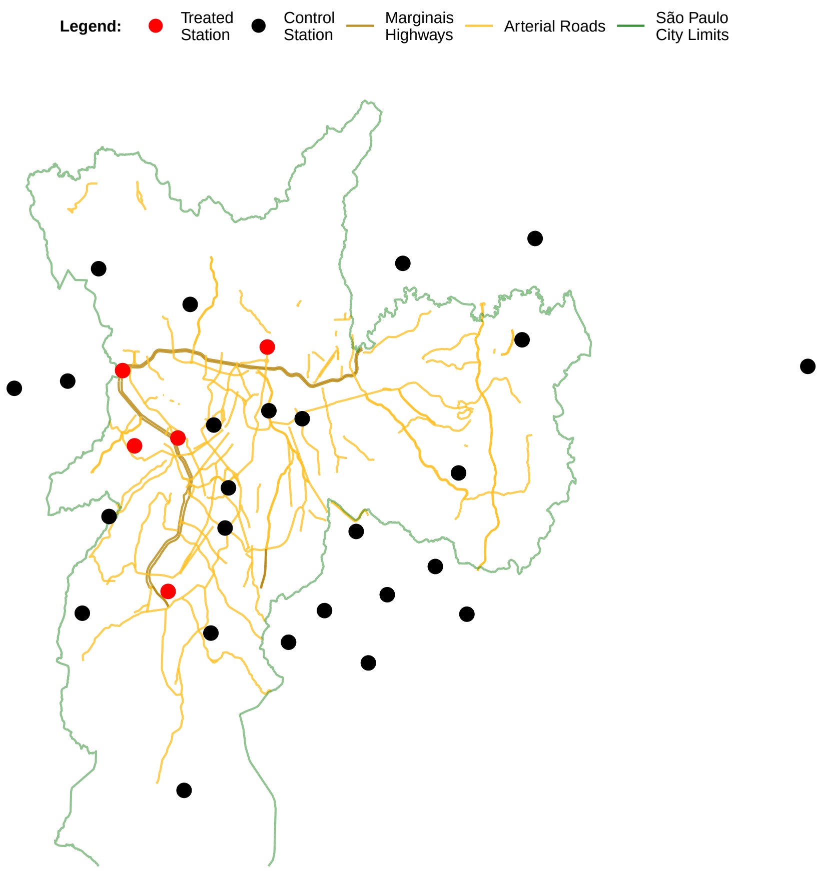
Taken together, these results provide evidence that the effects of speed limit reductions were not restricted to treated roads. Instead, there were significant policy spillover effects on nearby never-treated roads. First, we find a reduction in the number of speeding tickets on these nearby never-treated segments, thus indicating an adjustment in driver behavior. We also observe a decrease in road accidents that was inversely proportional to the distance of segments to the treated areas. These results suggest that speed limit reductions may affect driver behavior in ways that extend beyond a specific treatment zone. With respect to the exclusion restriction in our main econometric tests, these results support the exclusion of never-treated segments located within 1,600 meters of treated roads from the control group. By excluding non-treated segments nearby treated areas, we eliminate possible bias due to the confounding effects of spillovers.

H Policy Effects on Air Pollution

Changes in speed limits may also impact air pollution, as vehicle emissions are a mechanical function of engine speed. However, the expected impacts of the policy are not straightforward, since the relationship between vehicle speed and emissions is non-linear and is specific for different pollutants (van Benthem, 2015). The empirical evidence on the impacts of speed limit changes on air pollution is mixed, with at least one paper finding imprecise effects and the other two papers finding no effect (Folgero et al., 2017, van Benthem, 2015, Bel et al., 2015).

To evaluate the possible impact of the speed limit changes on air pollution in São Paulo, we scraped hourly pollution data from the São Paulo Environment Agency Air Control Website (https://cetesb.sp.gov.br/ar/qualar/). The system includes 30 air monitoring stations distributed in the metropolitan region of São Paulo. We divide the monitoring stations into 2 groups: treatment and control. We define the treatment group as the stations located up to 3 miles to the Marginais Highways, which is consistent with the threshold used in prior work van Benthem (2015). The control group is comprised of stations located farther away from that distance threshold. Figure H.1 maps the location of monitoring stations included and their treatment status as defined above.

Figure H.1. Air Monitoring Station by Near-Treatment Status



We estimate the following model:

$$log\left(y_{it}\right) = \alpha_i + \beta_t + \left(\sum_{m=2014-01}^{2017-12} \gamma_m \cdot D_{it}^m\right) + \zeta \cdot X_{it} + \varepsilon_{it} \tag{8}$$

Where y_{it} is the concentration of pollutant measured on station i at time t. α_i and β_t are respectively station and time fixed effects. D_{it}^m is an indicator variable that only takes the value of 1 for the treatment group of stations for each month m. The omitted category is June, 2015 – the first month preceding the speed limit reduction. The coefficients γ_m estimate the average changes in pollution measured at treated stations relative to control stations. X_{it} are station time covariates that include air humidity. wind speed, temperature and radiation.

Figure H.2 plots the γ_m coefficients by month for each major pollutant available in our dataset. The results do not indicate any clear or sustained pattern of air pollution effects associated with the treatment stations after any of the policy changes observed in our study period.

Figure H.2. Changes in Air Pollution at Near-Treatment Stations