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

Amanda Ang Peter Christensen Renato Vieira*

October 18, 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 accidents by 30% on treated road segments while not affecting traffic volume. We find that camera-based enforcement may substantially augment the effect of the speed limit reduction. We find that speed limit *increases* on major urban highways reduced the trip times by 7.5% during off-peak periods, though we find no significant effects in peak hours. We estimate that the social benefits from the reduction in road accidents are at least 29% 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.

Key words: Speed Limit Changes, Road Accidents, Travel Time
JEL Classification: H23, Q58, R41

*We thank participants at the University of Illinois PERE Seminar for comments.

1 Introduction

Road injuries are the leading cause of unnatural deaths worldwide, representing 27.1% of all human unnatural deaths (1.3 million fatalities per year) (WHO, 2015). The social cost of road accidents is also high, corresponding to approximately one third of all external costs related to private transportation (Parry and Small, 2005, Parry et al., 2007). In an effort to address this worldwide problem, the UN World Health Organization (WHO) declared the present decade (2010-2020) the "Decade of Road Safety" and advanced the ambitious goal of averting 5 Million road fatalities during the 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 versus 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.

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 these policies and the focus on speed limit regulations as a core component of the strategy advocated by the WHO is that vehicle speed is strongly associated with the probability and severity of road accidents. A growing body of empirical evidence overwhelmingly supports this claim (Archer et al., 2008, Musicant et al., 2016, OECD/ECMT, 2006, De Pauw et al., 2014, Elvik, 2013, Li and Graham, 2016, Sayed and Sacchi, 2016, Vadeby and Forsman, 2017, Woolley, 2005). However, reducing speed flows may pose an important welfare cost as commuters face longer journeys. And while well-enforced speed limits tend to

[1]These are mainly cities in developed countries. Examples include the cities of New York, Boston, London, Paris and Stockholm

reduce vehicle speeds, the empirical literature has provided little direct evidence of the effect of regulatory change on benefits from accident reductions and is even less clear on the magnitude and significance of these effects on total commuting time (Archer et al., 2008, Nitzsche and Tscharaktschiew, 2013, Heydari et al., 2014, Islam et al., 2014). 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 commute 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 in a unique empirical setting to provide the most comprehensive set of estimates to date on the effects of reduced speed limits in a major city 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. However, the policy became highly contentious and in early 2017, the speed limit on urban highways reverted to pre-reduction levels. We exploit the temporal heterogeneity of these changes to identify the impacts of the policy on costs and benefits, using a combination of detailed data on the universe of traffic accidents, ticketing from on-road traffic cameras, and real-time trip durations from google's transit API.

This study builds on other recent work that uses real-time web routing services to evaluate the impact of urban transportation policies on road or highway segments (Hanna et al., 2017).[2] With respect to the analysis of policy impacts on travel time, our study is novel in combining a city-wide sample of representative trips 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 suggest that this is an important methodological choice that has a bearing on interpreting reduced form effects of transit policy, as well as

[2](Akbar et al., 2017) use a similar methods to study the cost of congestion in a structural framework.

on extensions to benefit-cost analysis and understanding distributional impacts.

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 analyze the effects of speed limit changes in a developing country and on urban roadways, the key transportation corridors in one of the most highly congested cities in the world and also the locus of road casualties in Brazil (SP, 2017). It is not clear that the available findings from highways in the United States will generalize to the developing-country setting. Our findings suggest that while speed limit reductions in São Paulo have been benefit-enhancing for road users, the additional commute costs can approach the range of benefits estimates in São Paulo, highlighting the importance of careful analysis and design when considering road safety policies in highly congested cities of the developing world.

Our results indicate that the 2015 speed limit reductions reduced road accidents by at least 30% on treated road segments.[3] Importantly, increased enforcement and monitoring augments these effects. We find that roads where speed limit reductions occur alongside contemporaneous onset of camera-based enforcement experience an additional 9-10% reduction in accidents. We find fairly modest effects of the speed limit change on commute times. We estimate that travel speeds on treated highways increased by 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 speed limit changes in a welfare framework that compares the social cost of reduced speed to travelers to 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 outweigh the costs of longer commutes by 1.29-2.88 times.

This paper makes a final contribution by examining the extent to which speed limit

[3] We are aware of one other study (Jardim, 2017) that investigates the impacts of the São Paulo speed limit reductions on speed and road accidents.

reductions have progressive/regressive impacts, which is an important and unresolved issue in the transportation literature (van Benthem, 2015). The distributional analysis reveals that speed limit reductions have strongly progressive impacts in developing country cities such as São Paulo. 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 commutes on treated roads. This is expected. However, we also find evidence of a striking difference in the distribution of the benefits from accident reductions across income groups. In particular, we find that 86% of the benefits of reductions in accident damages in São Paulo accrue to lower-income residents, who bear a disproportionate share of the accident risk as pedestrians and motorcyclists. Distributional concerns may be a key issue when considering road safety policies in cities such as São Paulo.

The remainder of this paper is divided as follows: Session 2 describes the background of the speed limit changes investigated in our study. Session 3 details the data sets used for our analysis, and Session 4 presents the empirical strategies that we use to identify the policy impacts on accidents and travel time. On Session 5, we compare the costs and benefits of the policies, including our distributive analysis. Session 6 compares our results with the literature and Session 6 concludes.

2 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. Table 1 presents characteristics of motorized trips made in São Paulo on a regular weekday. 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 trip in São Paulo is 8 km, though the mean trip duration is 51 minutes.

2.1 Speed Limit Reductions in 2015

Travel-related injuries are a major problem in São Paulo. During the period 2005-2014, 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 OECD average. Given the 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," which involved a target for reducing road mortality in the city to 6 deaths per 100,000 inhabitants by 2020 (CET, 2016). As part of the project, 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) In July 20, 2015, the speed limit of the main urban highways of the city (Marginais)[4] was reduced from 90km/h to 70km/h.[5] Over the following six months, speed limits on city arterial roads were successively reduced from 60km/h to 50km/h[6] (CET, 2016). By the end of this process, the speed limits on approximately 570 km roadways had been changed.[7] These road segments constitute 4% of the road network and 29% of private vehicle VMT in São Paulo.[8] Figure 2 maps the roads where speed limits were reduced, indicating the final speed limit in each treated road segment after the 2015 changes.

Figure 3 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 semester of 2015.

[4]The name "Marginais" comes from the location of these highways, which run through the banks (margens in Portuguese) of the Pinheiros and Tietê rivers.
[5]These values correspond to the speed limit reduction in the express lanes of the Marginais. In the intermediary and local lanes of the highways, speed limit was reduced respectively from 70km/h to 60km/h and from 70km/h to 50km/h.
[6]The only exceptions were the "Corredor Norte-Sul" (North-South Corridor), where the speed limit was reduced from 70km/h to 60km/h, and some few arterial roads where the speed limit was reduced to 40km/h.
[7]This figure does not weigh treated segments by the corresponding number of lanes.
[8]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.

Another major component of the road safety program was the concomitant expansion of speed control cameras, which is the primary method of speed limit enforcement in Brazil. Automated traffic cameras register vehicle speeds and issue speeding tickets to vehicles that are speeding.[9] (CET, 2016). Figure 4 plots the growth of speed control cameras 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. Figure 5 compares the location of cameras installed before and after the first speed limit reduction implemented on July 20, 2015. Figure 6 maps the location of the new cameras installed after that same date. While 55.9% of cameras installed before July 20, 2015 were located on road segments which 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, (3) road segments with speed limit reduction, and (4) road segments with speed limit reduction and camera-based enforcement.

2.2 Marginais Highways Speed Limit Reversal in 2017

In January 2017, the speed limit on Marginais Highways reverted to pre-2015 values (raised back from 70 km/h to 90 km/h). This measure was a major campaign proposal of the incumbant mayoral candidate during the electoral process and was adopted during the first month of the (newly elected) mayoral term. The debate about urban speed limits was a contentious topic during the political campaign.[10] However, contrary to the speed reduction of 2015, the speed limit reversal of 2017 was restricted to the Marginais

[9]The fees for speed limit violations are defined by the National Traffic Code (Código de Trânsito Brasileiro). In 2015 the values 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

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

Highways, and the speed limit in the city arterial roads did not revert.[11]

3 Data

This study evaluates the impacts of speed limit changes adopted in the roads of São Paulo. While the speed limit reductions were aimed at reducing road accidents, the speed limit reversal was defended during the city electoral campaign as a measure to reduce commuting time. We focus our analysis on these two outcomes. Figure 7 summarizes the policy timeline and span of data sets used in this analysis:

- a - Road segments with speed limit changes - (2015 & 2017)
- b - Traffic accident counts - (2012-2017)
- c - Traffic control cameras and ticket counts - (2014-2017)
- d - Estimated real-time trip durations (from a Web API) - (2016-2017)

3.1 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 when the change would be implemented. These announcements also described the existing speed limit of these segments and the new limits that would be adopted.[12]

[11] Concomitant with the speed limit reversal of 2017, compensating safety measures were adopted to attenuate the possible increase in accident risk. These measures included: the construction of elevated road steps on pedestrian crossing points at Marginais feeding lanes; placement of signs warning drivers about the presence of pedestrians; bus operators were instructed to provide additional safety courses to bus drivers; traffic agents with speed control pistols were placed throughout the Marginais Highway (CET, 2016). It is important to bear in mind three key differences between the reversal of 2017 and the original reductions of 2015 that limit the direct comparison between the policies: 1) The reversal did not include arterial roads; 2) the original reduction was accompanied by an extensive expansion of camera enforcement which was effectively unaltered in 2017; 3) Compensating safety measures were adopted in 2017 to attenuate a possible hike in accident risk. However, it is important to notice that these differences will not have a bearing on our main results because we focus our analysis of policy impacts on the 2015 speed limit reductions.

[12] Appendix A shows the information from one of these announcements and summary information for all 37 announcements used in this study.

We collected all such reports from the agency website and, using their exact geocoded location and date, identified the road segments and timing of speed limit changes. In total, the 37 reports used in our study describe the speed limit changes implemented on 202 different roads in São Paulo, including approximately 570 km of treated road segments. Before the actual speed limit reduction on each segment, the traffic agency of São Paulo placed a series of traffic signs and banners in those segments indicating the upcoming speed limit change.[13] These warning may have caused anticipatory effects in the weeks leading up to a change. We address potential bias from anticipation by excluding observations of segments from the period immediately before the speed limit change in each road.

3.2 Traffic Accidents

We construct a panel dataset using data from the São Paulo Traffic Agency yearly reports of road accidents from 2012 to 2017. These reports compile information for all road accidents registered within the city of São Paulo by the police departments, traffic agents', hospitals, and morgues (CET, 2017).[14] 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 2 presents 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. It is worth noting that 5,016 (3.10%) of these accidents and 276 (4.6%) of 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 from 2017.

We utilize the information specific to each accident to calculate the monetary cost of

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

[14] 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 opened in March 31, 2017, LAI request 25,968 opened in November 1, 2017, and LAI request 30,818 opened in May 23, 2018.

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. [15] In the case of road fatalities, we use the Value of Statistical Life (VSL) of U$ 1.695 Million[16] estimated for Brazil by Viscusi and Masterman (2017). We separate accident costs into their two components, internal and external. We define the internal cost as costs that are born by drivers who are responsible for the accident. We define the external cost as costs imposed on other individuals, such as pedestrians and other drivers. Following van Benthem (2015), we calculate the internal cost of each accident by adding the total accident cost that is associated with vehicles, drivers and passengers, and dividing this value by the total number of vehicle involved in each accident. All remaining cost is assumed to be external.

3.3 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 Google Directions API, which identifies an optimal route for the provided 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 in research on transportation economics in this and similar developing country settings. We note two additional advantages of the API data relative to more conventional observations of traffic counts and vehicle speeds on highways. First, the outcome measure that we are generally interested in when studying transit 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

[15] Appendix C presents all the parameters from IPEA (2016) used in our study.
[16] In USD of 2015.

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 API provides the outcome measure directly and adjusts in real-time based on evolving conditions. The key assumption is that that travelers will use the most efficient paths from origin to destination, as recommended by Google's routing algorithm.

The sample of representative journeys 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 in a regular weekday. The survey collected detailed information about 46,861 trips taken by 8,115 households. Using the origin and destination coordinates of motorized trips reported in the survey, we ran a series of queries based on the day and time that each trip is taken to construct a panel of trip-specific travel times given real-time traffic conditions. Table 3 presents descriptive characteristics of the simulated trips from our study. In total, we simulated 1.47 million trips between July 2016 to September 2017. Out of this total, 243.7 thousand trips had at least 400m running through the Marginais Highways. We define this subset as trips that used the Marginais Highways. 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, and the average length 8.31km. In the case of trips using the Marginais highways, the average length was 122% longer, although the average duration was only 92% longer. Therefore, although trips using the Marginais highways were considerably longer in length, they tended to have a higher average speed. It is worth noticing that even among the subset of trips that used the Marginais highways, the mean share of trip length going through those highways was 22%.

3.4 Electronic Traffic Tickets and Cameras

Our study also examines traffic tickets issued by traffic monitoring cameras in São Paulo. These devices automatically identify traffic violations issuing tickets that are mailed to the drivers' residences and are the main form of traffic enforcement in the City.[17] Each ticket includes information about: (1) the type of traffic violation that was registered, (2) the date and hour of its occurrence, and (3) its location. Table 4 summarizes the sample of traffic tickets, which includes all electronic tickets issued in São Paulo between 2014 and September of 2017. In total, more than 35 Million traffic tickets were issued during that period, averaging 9.46 Million tickets per year. The total number of tickets increased by more than 53% in 2015, 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 tickets and cameras in three different ways. First, we identify the presence of speed monitoring cameras on all segments included in our analysis, identifying precisely when these cameras are installed or discontinued. We use this variable to estimate the effects of interactions between the speed limit reductions and the 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 begin to behave more carefully in general after the policy, then we should observe a reduction in speeding tickets on segments that are not treated. This type of spillover could lead to downward bias in estimate of policy effects. Finally, we use the volumes of tickets that are *unrelated* to speeding to construct a proxy for driver volumes per segment over time. The city of São Paulo adopts a driving restriction scheme that limits the circulation of 20% vehicles at peak-hours in the central area of the city. [18] Here we assume

[17] Data were accessed from the City of São Paulo "Painel Mobilidade Segura" website

[18] The restriction is based on the final digit of vehicle's license plates. 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, vehicles with final digits 1 and 2 are restricted to circulate in the São Paulo Downtown Area. Appendix D shows the Driving Restriction

that the number of non-speeding violations per camera is a function of the number of cars circulating on monitored road segments.[19] We use this proxy to test for evidence of substitution away from treated roads after the speed limit reductions.

4 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 examine the effect of the speed limit increase of 2017 on commuters' travel time.

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

In the absence of a randomly assigned treatment, we exploit temporal and geographical heterogeneity 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 repeat observations of accidents on road segments that were treated at different points in time as well as onsegments that were never treated. We estimate the effects of the speed limit reductions using a semi-dynamic event study (Borusyak and Jaravel, 2016).[20] The primary assumption underlying identification in this design is that of parallel paths: changes in road accidents observed on a treated segment follows a path parallel to that observed on road segments that have not yet been treated.

Area of São Paulo and its overlap with the streets which had their speed limit altered in the period of our analysis.

[19] We acknowledge that this measure is not a completely perfect proxy for traffic volume. First, we miss any information about non-restricted periods. Moreover, the measure would be biased by unobserved factors that affect the number of tickets but may not be associated with traffic volume. However, it is the best available measure of traffic volume per segment and it is we maintain it is a valid proxy for peak hours as it would identify non-marginal changes in road usage per segment in that period.

[20] Refer to Borusyak and Jaravel (2016) and Abraham and Sun (2018) for recent reviews of event study research designs.

4.1.1 Semi-dynamic event study with controls

In addition to this semi-dynamic event study specification, we estimate our empirical model using 4 alternative samples of control segments. Sample (1) includes all treated segments and introduces the most general sample of controls: all never-treated avenues in São Paulo. There are two concerns with this sample: (a) new speed limits could potentially affect driver speeds and accident risk on nearby roads and (b) the selection of treated segments is non-random. We evaluate the potential for behavioral spillovers using data of electronic speeding tickets and find evidence that number of speeding tickets per camera decreased on segments within 1.6 km of treated roads[21]. However, we find no evidence of spillovers beyond 1.6 km of treated roads. Therefore, in Sample (2), we exclude all control segments located within 1.6 km of any treated road.

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 subsets treatment and control groups to segments with more than 12 accidents in the study period.[22] Sample (4) constructs a matched sample where each treated segment 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 controls. We control for secular changes in driver behavior across the time series with a linear time trend and 2 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 the city of São Paulo.

Figure 8 maps the segments included in each of the samples described above. Each panel of the figure shows the treated and control groups used on samples (1)-(4).[23] 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

[21] Appendix F describes this result in further detail.

[22] This threshold corresponds to the mean number of total accidents per segment in the subset used in Sample (2).

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

(3) imposes a considerable restriction on control and treatment segments. Panel D shows that the matching strategy places greater restriction on the control group.

Figure 9 plots the raw time series of road accidents on the treatment and control groups used in samples (1)-(4). The figure normalizes the average number of accidents per km for both groups based on the values observed in June of 2015, which is the last month before the first speed limit reduction in the 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 is coincident with the onset of the speed limit change.

We use the following estimating equation to estimate the event study model:

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

where y_{it} is the number of accidents observed on segment i during month t. We use a Poisson regression to estimate the count model and report estimates from an equivalent linear specification in Appendix E.[24] On the right-hand side of Equation 1, α_i is a segment fixed effect that captures the average number 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. 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. 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.[25] For instance, γ_1 indicates the average relative change in accidents on treated segments in the first three months after speed limit reduction.

[24]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.

[25]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).

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.[26] 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 of speed enforcement.

In our baseline specification, we exclude observations from the quarter immediately preceding the speed limit change due to the possibility of confounding effects from anticipatory behavior resulting from the placement of banners and signs announcing upcoming speed limit changes.[27] Following the approach defined by Borusyak and Jaravel (2016), we conduct independent tests for pre-trends in subsection 4.1.2 and then omit leads for the quarters preceding the speed limit reduction in our primary specifications.[28]

4.1.2 Tests for differences in pre-treatment accidents trends

If the parallel paths 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 paths assumption in the pre-treatment period by extending our baseline specification with leads of treatment associated with relative-quarters before the speed limit reduction in each segment:

$$y_{it} = \alpha_i + \beta_t + \left(\sum_{Q=-8^-, Q\neq -2}^{-1} \xi_Q \right) + \left(\sum_{Q=1}^{7^+} \gamma_Q \right) + \zeta \cdot C_{it} + \eta \cdot C_{it} \cdot SLR_{it} + \varepsilon_{it} \quad (2)$$

[26]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

[27]Figure B.1 on Appendix B shows an example of one these signs.

[28]In subsection 4.1.2 we extend the baseline specification t include leads of treatment and tests for significant differences in pre-treatment trends between control and treatment groups. We find no evidence of significant pre-treatment deviations outside of the (excluded) anticipatory period immediately preceding treatment.

If the assumption of parallel paths holds, then all coefficients ξ_Q should be equal to zero.[29] Figure 14 plots the coefficients γ and α for each of the segment samples used in Model 1. Results very similar 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 path for the year preceding treatment. None of the coefficients associated with periods preceding treatment are statistically different from zero, providing support for the parallel paths assumption. We also note that the coefficients associated with the quarter immediately preceding the speed limit reduction do suggest some 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 estimates of policy effects.

4.1.3 Estimates of the effect of speed limit reductions

Table 5 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 an immediate effect of 9.1-16.2% in the first quarter following the reduction that grows to 21.5-34.4% over a period of two years (8 quarters). 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 nearby treated roads where driver behavior 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 30.0-32.7% in the final quarter

[29]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.

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 as controls are larger in magnitude, suggesting an immediate effect of 17.6% that grows to 40.5% over the first two years. 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 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 range 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).

4.2 Testing for effects of route substitution

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 started driving more slowly. However, an alternative channel through which the speed limit reductions could affect the accidents involves substitution. If drivers substituted away from treated roads that had become slower, then this substitution would imply in fewer vehicles driving on treated roads and consequently, fewer accidents. To test that alternative mechanism, we use data on tickets that result from non-compliance with the city's driving restrictions. These tickets are not related to speeding behavior and serve as a proxy for traffic volume per segment. We test the effect of the speed limit reduction on the ticket/traffic volumes using a dynamic event-study model that mirrors our main specification:

$$Z_{it} = \alpha_i + \beta_t + \sum \delta_{it} + \varepsilon_{it} \tag{3}$$

The dependent variable (Z_{it}) in this model is the log of driving restriction tickets issued on segment i during month t. The model is estimated using the subset of road segments that possess a driving restriction camera during the entire study period. The hypothesis tested with this model is that if the speed limit reduction caused lower traffic volumes on treated segments, then the coefficients τ_{it} would be negative and statistically significant.

Figure 11 plots the coefficients δ_{it} corresponding confidence interval (95%) from Model 3 as a function of relative time to the speed limit reduction. These results suggest that there may have been a slight (non-significant) reduction in driving restriction tickets immediately following the reduction, test routing alternatives, though they resume to pre-policy volumes within the first 5 quarters of the new policy regime. Assuming that the volume of driving restriction 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 that would bias our estimates of accident reductions on treated segments.

4.3 Why did the effect of speed limits increase over time?

Our main results suggest that the impacts of the speed limit reduction in Sao Paulo were dynamic: we observe a substantial immediate effect that then increased gradually over time. The mechanism underpinning dynamic effects in response to speed limits is not immediately clear. Was there a period of behavioral adjustment to the new speed regime following the policy? Or do drivers comply immediately with the new policy, but collision risk falls more gradually due to a more complicated set of responses in the new equilibrium? Or are there unobserved changes continuing to occur on treated roads that we have not accounted for in our model?

The most obvious hypothesis is that there was a period of adjustment to the new regime after policy adoption. That is, following the speed limit reductions, not all drivers may immediately comply with the policy. Given strict camera-based enforcement, changes in driver behavior may involve a behavioral response to infractions and penalties for dangerous drivers. To test this hypothesis, we compare changes in speeding tickets issued on treated segments to tickets on segments that were not treated. This exercise closely resembles the analysis for driving restriction tickets discussed in the previous subsection. We estimate Equation 3, substituting the log of speeding tickets per segment as the new outcome of interest (Z_{it}).

Figure 12 plots the estimates from this model. The results illustrate a sharp and immediate **increase** (+25%) 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 a year, the number of tickets then begins decreasing and reaches pre-policy levels before spiking again in the final quarter of the sample.

4.4 Effects on Highways versus Arterial Roads?

One final question related to the effect of speed limit reductions concerns whether effects are different on arterial roads, where limits changed from from 60km/h to 50km/h, and highways (Marginais), where the reduction was from 90km/h to 70km/h. We examine this question using a standard model of heterogeneity in treatment effects. Specifically, we estimate the following extension of our baseline empirical model where we add the indicator variable H_{it} which takes the value of 1 for observations of segments from the Marginais Highways after their speed limit reduction and a value of 0 otherwise:

$$y_{it} = \alpha_i + \beta_t + \left(\sum_{Q=1}^{7^+} \gamma_Q\right) + \mu \cdot H_{it} + \zeta \cdot Cam_{it} + \eta \cdot Cam_{it} \cdot SLR_{it} + \varepsilon_{it} \tag{4}$$

In this model, the average changes in road accidents on the Marginais highways is captured by the μ coefficient. Table 6 presents these estimates using the different (control) samples used in our study. Overall, the point estimates suggest that the reduction in accidents on the Marginais Highways may have been about -12% larger than effects on arterial roads, but are not sufficiently precise to rule out homogeneous effects on highways and arterial roads at a 5% confidence level.

4.5 Did São Paulo's Road Safety Policies Increase 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 before and after the policy change. Our baseline empirical strategy is given by the following equation:

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

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.[30] Ma_i indicates the share of each trip that takes place on the Marginais highways, and I_d indicates if the query was made after the speed limit increase in January 25, 2017. Therefore, while the coefficient γ captures the average change on estimated travel time for all trips, the coefficient β indicates the additional travel time change that was specific for trips using the Marginais proportional to the share of trips made on those highways. Moreover, X_{hd} is a vector of covariates that include the occurrence of rain in the moment of the query and if date d was a holiday in São Paulo.

It is possible that the effects of the speed limit reduction may not be constrained to trips taken in the Marginais. Instead, travel time reductions could also occur on nearby roads due to spillover effects. To account for these possible effects, we include in our specification a set of terms that identify the ratio of trips that take place within buffers of certain distances L from the Marginais Highway. In our baseline specification, we include three levels of non-overlapping buffers with respective distances of 1km, 3km and 5km. Figure 13 illustrates the areas delineated as controls through this process.

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

Table 7 reports the results from the regression model specified by equation 8. 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. This effect accounts for an overall reduction of 1.8% in travel time for all trips in our sample irrespective of the Marginais effect. Consistent with expectations, these estimates indicate that rain led to an average increase of 1.9% in travel time and holidays trips were on average 10% faster.

In Column 2, we include the covariates that measure the portion of a trips that takes place in spillover zones that may have been indirectly affected by the speed limit change in the Marginais Highway. The inclusion of these variables reduces the main treatment effect to 5.8%. 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 later was not statistically significant. On column 3, we include month-specific fixed effects, which that do not meaningfully affect any of these estimates.

Finally, in Column 4 report estimates from a specification that separate the main treatment effect into effects on trips taken during peak hours and effects on trips during the off-peak period. These results indicate that most of the travel time reduction in the Marginais occurred in 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 bind.

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 14 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.

Summarizing the results on reduced-form effects of speed limit changes on accident reductions alongside effects on trip durations, we find that the speed limit reductions of 2015 resulted in a long term reduction of 30%-39% reduction in road accidents. Larger effects were observed on the Marginais Highways and on segments where speed monitoring cameras were present. We do not find any evidence of traffic volume reduction associated with the policy. We find that trips taking place on the Marginais became approximately 6.5% faster following the speed limit increase of 2017, however that effect was concentrated and was only significant for trips taken during off-peak hours.

5 Cost-Benefit Analysis

In this section, we compare the social costs and benefits of the speed limit changes that were implemented in São Paulo. We begin by estimating the monetary value of road accidents and travel time using standard parameters from the literature. We then construct counterfactual scenarios that allow us to compare the monetized benefits from reduced accidents to the cost of 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. Finally, we exploit the individual-level characteristics of travelers in our datasets to evaluate the distributional implications of the policy.

5.1 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 results from Sample 4 as our central estimates. 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.

Additionally, we also present the results based on the reduced form results from Sample 5, which completely excludes control segments.

In both cases, we use the final quarter of data (2 years post-implementation) as a best approximation of the long-run effects from the model that includes specific effects for the Marginais Highways. Based on these point estimates, we construct two counterfactual scenarios with alternative policy setups. First, we analyze the case where speed limit reduction was adopted but no additional cameras were added to treated roads. Next we evaluate the case where speed limit reductions were not implemented.

To make results comparable with travel time gains, we restrict our analysis to accidents observed on business days[31] in the first year after policy adoption (2016). The monetary cost of accidents is estimated based on accident parameters from IPEA (2016) and the value of statistical life calculated by Viscusi and Masterman (2017) for Brazil.

Table 8 reports the results of this analysis. First, the table shows the total number of accidents on treated roads that were observed during the business days of 2016. It also presents the total monetary cost associated with these accidents. Next, the table shows the estimated number of accidents and its corresponding monetary costs on different counterfactual scenarios. First, we construct the counterfactual scenarios using the point estimates from the reduced form model using Sample (4) of road segments, and then, we consider the case of Sample (5). In both cases, we construct two counterfactuals, one case where speed limits reductions are adopted but new cameras are not added to the roads. Next, we consider the case where lower speed limits were not implemented.

Because the policies have reduced road accidents, all counterfactual scenarios present more accidents than observed in reality. Regardless of the set of coefficients used, the results for cameras were considerably more modest if compared to the effects of speed limit reductions. That is because while the coefficients for the effect of cameras were significant and of similar magnitude to the speed limit reductions, the effects of cameras were restricted to the subset of treated road segments where new cameras were added. In contrast, the effects of speed limit reductions affect all treated road segments.

[31] The household travel survey used to compute travel times is only representative for business days, so we need to use the same restriction for accidents so the values can be compared.

As expected, the results from the counterfactuals based on Sample (4) were smaller if compared to the results from Sample (5). In the first case, total policy benefits of speed limit reductions were estimated in R$ 582 million. Meanwhile in the case of results based on Sample (5), that number increases to R$ 880 million. Throughout all results, the Marginais Highways accounted for 11% to 16% of policy benefits.

5.2 Benefits from the 2017 Speed Limit Increase

Next, 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 comparison our results and Van Benthem's study in 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 wage rate (Wolff, 2014).[32] Therefore, as an alternative and a possibly more reasonable parameter, we calculate policy benefits using the Victoria Transport Policy Institute (VTPI) 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 (Institute, 2016).

Table 9 reports the results of our calculations based on these two different parameters. The first set of columns refer to the results using a the 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 70km/h in that year. Next, we calculate two distinct counterfactuals for the speed limit increase to 90km/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

[32] The USDOT recommends assigning half of the hourly wage for non-business trips within local urban settings (DOT, 2014).

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 exact individuals affected by the policy and estimate their corresponding welfare benefits according to individual-specific parameters. This approach 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 individual specific VOTs, 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. 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 the speed limit increase.

5.3 Comparing the Cost and Benefits of Speed Limit Changes

We proceed by comparing the benefits associated with reduced accidents from the speed limit reductions of 2015 with the reduced costs associated with travel time savings from the policy reversal in 2017, which are different events. We begin by noting that the total estimated effects of these policy changes cannot be directly compared because 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 Highway and was not accompanied by any substantial changes in enforcement. Therefore, to hone the comparison of policy costs and benefits, we focus on the speed limit changes on the Marginais Highway. For these particular roads, we utilize the following results:

1) the estimates of benefits due to accident reductions (R$ 73.5 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 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.[33]

If we assume that travel time effects observed in 2017 are symmetric but inverse to the impact that would be observed in the speed limit reduction, we are able to provide a more direct comparison the benefits and costs associated with the 2015 speed limit reduction in the Marginais Highway. Given this assumption of symmetry in effects, we calculate a benefit/cost ratio that ranges from 1.29 if we use a conservative upper bound for VOT and a lower bound for accident effects, to 2.88 if we use the (preferred) VTPI VOT and the preferred estimate of accident effects from our matched sample of segments.

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 with road accidents. Given the underlying uncertainty in this parameter, it becomes useful to identify the breakeven VSL – the minimum VSL for which a speed limit reduction would still be socially beneficial. Figure 15 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); 3) the EPA recommended VSL of R$ 20.1 million for the USA. The horizontal lines on the graph depict the total cost of the speed limit reduction given our alternative VOTs parameters.

The results of this analysis indicate that the speed limit reductions in the Marginais Highway would yield net benefits if the value of a statistical life in our sample is greater than R$ 2.76 million. That is about 60% of our central VSL. However, if we consider the VTPI VOT parameters, the breakeven VSL would approach zero: the reduction of costs

[33]In this cost-benefit comparison, we do not include spillover effects from neither accidents nor 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.

from non-fatal accidents would be sufficiently large in themselves to compensate for the increases in commuting time. If we consider the VSL suggested by the USA EPA, the policy benefits would be more than 3.6 times larger than our maximum estimated policy costs.

5.4 Distributional Effects of Speed Limit Changes

Next, we use our central case parameters to evaluate the distribution of policy costs and benefits to 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. Figure 16 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. We also 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 exact same trips on the Marginais Highway, then we assume that their corresponding travel time after the speed limit reduction to be the same. We compute the distribution of costs using a single average VOT for consistency with the VSL parameter, which is the population average for Brazil.

Figure 17 plots the mean costs and benefits of the speed limit reduction for the individuals 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. The figure indicates a clear pattern in the distribution of costs and benefits across income groups. While the benefits are larger for individuals with low educational attainment (no primary education, primary education, and secondary education) the travel time costs have a disproportionately large effect on individuals with high educational attainment (college education). College educated drivers are the only group for which the costs of the speed limit reduction exceed the benefits. The policy delivers benefits to most income groups in São Paulo and appears to be strongly progressive.

We are unaware of any theoretical result or other empirical evidence to suggest that (lower) speed limits have a progressive impact. We therefore investigate the mechanisms that underlie these distributional effects using two pieces of information: 1) the distribution of road fatalities by educational attainment (responsible for largest share of accident damages); 2) the use of private vehicles by educational attainment (primary mechanism underlying policy cost). Figure 18 reports these results, which plots the proportional share of private vehicle use and road fatalities 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.

Two clear facts become evident from these graphs: (1) higher income individuals own cars and drive them on the Marginais Highway (the distribution of Marginas drivers is even more skewed toward the high income group). We do not find this fact surprising at all. It seems intuitive that the same groups would disproportionately benefit from a reduction in accident risk on the very same roads. However, we find just the opposite. The relative distribution of road fatalities is larger for the individuals with a primary education, and in the case of pedestrians, it is also larger for those with no primary schooling. 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 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 reasons for these differences in fatality rates may include differences in the proportion of travelers who use motorcycle, the ability to afford safety features on vehicles, and differences in driving behavior.

6 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 compares costs and benefits in 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 pirmary benefits and costs from the policy, which increases the value of a comparison of primary results. It is important to note that there are important differences with respect to the setting evaluated in the papers. While VB examines speed limit changes from more than 20 years ago on regional freeways in western USA,[34], whereas our study examines a policy change from 2015 on urban roads in a metropolitan area of the developing world. Therefore, when comparing the results from both papers, it is important to acknowledge that each of these distinct dimensions may play an important role in explaining the differences in estimates.

Table 11 summarizes the comparable results between the two studies.[35][36] 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 system. The primary difference in the results presented between the two studies concerns impacts on accidents. While the present study documents a reduction of 43% on the Marginais Highways, VB results for American roads identified an average effect of 14%, although he found an effect of 44% in the case of fatalities. In our study, we were not able to separate with sufficient precision

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

[35] 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.

[36] In addition to the sources of costs and benefits studied in this paper, van Benthem (2015) include the effects of the 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 by the author. Our work on the estimation of policy effects on pollution is still 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.

the policy effect on fatal accidents, therefore we assume that the effect on fatalities was proportional to the policy effect on total accidents (43%). In both studies, if travel time values 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. There is an important source of contrast between the benefit cost ratios presented in the paper. While in the VB study the central estimate of the benefit/cost ratio was 2.21 the comparable ratio in São Paulo was 1.29. The relative breakeven VSL was about 22% higher in our study. Multiple factors contribute to these differences in ratios, but primarily, we have the lower ratio of accidents per vehicle-hour traveled (VHT) on the Marginais Highway in São Paulo, where there were 137 accidents per million VHT compared to 211 in the American Highways evaluated by VB. This difference is easily explained by the different average speed between our urban setting if compared to VB's rural roads. On the Marginais Highways, the traffic agency of São Paulo reported an average vehicle speed of 35.45 km/h in 2014. Meanwhile, average vehicle speed was of 96.8 km/h on the rural roads included in VB analysis. Even though A key contribution of the present study is demonstrable evidence that speed limit reductions on urban highways in one of the most highly congested cities in the world (where concerns about the costs of additional congestion and extended commutes make speed limits a voting issue for the population) have a net beneficial and progressive impact on the population.

In synthesis, compared to VB, our study has also identified that the gains associated with lower accidents are larger than travel time losses. This result was found while using a VOT that is admittedly likely to overestimate the costs of travel time if compared to recommended parameters from the literature. Given that we estimated the impacts of a speed limit reduction in a completely different setting from VB, the similarity of results supports the external validity for claiming that speed limit policies are an effective tool for reducing road accidents without imposing net welfare losses to society.

7 Conclusion

This paper evaluates the effect of policies that altered traffic speed limits in São Paulo Brazil. We show a series of speed limit reductions in 2015 resulted in a large reduction in road accidents and fatalities on treated road segments. This reduction in accidents cannot be attributed to road substitution or other confounding factors affecting pre-treatment accident trends. Measurements from more than 1 Million queries of trip durations using a sample of representative trips and a web API indicate that the estimated time in transit for users fell immeditaley following a speed limit increase adopted in 2017.

We combining these results with detailed information about the types of individuals affected by the policies and standard parameters from the literature to compute 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. Using information about the educational attainment of individuals who were victims of accidents and a representative sample of transit users in São Paulo, we find strongly progressive impacts associated with the speed limit reduction – the reduction in fatal accidents disproportionately benefit lower- and middle-income groups and travel time costs disproportionately affect wealthier individuals.

We acknowledge that our analysis is limited in severl important 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 also do not account for the policy benefits associated with pollution and health, which although uncertain, are estimated by van Benthem (2015) to double the assessment of policy benefits. Traffic safety programs and goals set by the WHO as part of the Decade of Road safety are typically based on concern about road accidents themselves. Our study provides evidence that speed limit reductions, even within cities that are concerned about additional congestion problems, can be rationalized on the basis of accident reductions alone.

An important component of the setting that is not comprehensively evaluated in this paper involves the camera-based traffic enforcement structure employed in São Paulo. In 2016, the city issued 6.7 million speeding tickets, more than half a ticket per resident. The local government of São Paulo collected approximately R$ 1.1 billion from these tickets, an amount that is larger than our overall assessment of gross policy benefits associated with all speed limit reductions adopted in 2015. Our estimates of the impact of traffic cameras themselves suggests that they have a modest impact on accident mitigation in general and during a change in speed limits. In principle, fees paid for speeding violations involve a transfer of resources, so they should not affect the assessment of social welfare impacts of the policy. However, given the magnitude of fees collected by the city, this system imposes non-negligible effects, particularly in terms of distributive effects, that we have not considered in our analysis and are worthy of further investigation.

The external validity of our results is clearly limited given the design of our analysis in Sao Paulo. Our results are consistent with those reported for highways in the United States. Several cities throughout the world are experimenting with stricter speed limit policies and the United Nations has outlined a goal of evaluation as part 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 emphaisze 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 Sun, L. (2018). Estimating dynamic treatment effects in event studies with heterogeneous treatment effects.

Akbar, P., Duranton, G., et al. (2017). Measuring the cost of congestion in highly congested city: Bogotá. Technical report, CAF Development Bank Of Latinamerica.

Archer, J., Fotheringham, N., Symmons, M., and Corben, B. (2008). The impact of lowered speed limits in urban and metropolitan areas. monash university accident research centre, victoria, australia.

Ashenfelter, O. and Greenstone, M. (2004). Using mandated speed limits to measure the value of a statistical life. *Journal of political Economy*, 112(S1):S226–S267.

Borusyak, K. and Jaravel, X. (2016). Revisiting event study designs. *Browser Download This Paper.*

CET (2016). Benefícios imediatos da redução das velocidades máximas permitidas o caso das marginais tietê e pinheiros. Technical report.

CET (2017). Acidentes de trânsito – relatório anual - 2016. Technical report.

DATASUS (2018). Informações de saúde (tabnet).

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

DOT, U. (2014). The value of travel time savings: Departmental guidance for conducting economic evaluations revision 2 (2014 update). *Office of Secretary of Transportation, US Department of Transportation.*

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.

Google (2009). Google official blog.

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

Heydari, S., Miranda-Moreno, L. F., and Liping, F. (2014). Speed limit reduction in urban areas: A before–after study using bayesian generalized mixed linear models. *Accident Analysis & Prevention*, 73:252–261.

Institute, V. T. P. (2016). Transportation cost and benefit analysis techniques, estimates and implications [second edition].

IPEA (2016). Estimativa dos custos dos acidentes de trânsito no brasil com base na atualização simplificada das pesquisas anteriores do ipea. Technical report.

Islam, M. T., El-Basyouny, K., and Ibrahim, S. E. (2014). The impact of lowered residential speed limits on vehicle speed behavior. *Safety science*, 62:483–494.

Jardim, F. B. (2017). *Estimando o impacto da redução da velocidade máxima nas vias de São Paulo e o valor estatístico de uma vida*. PhD thesis.

Li, H. and Graham, D. J. (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., Bar-Gera, H., and Schechtman, E. (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.

Nitzsche, E. and Tscharaktschiew, S. (2013). Efficiency of speed limits in cities: A spatial computable general equilibrium assessment. *Transportation research part A: policy and practice*, 56:23–48.

NYC (2018). Vision zero year four report. Technical report.

OECD/ECMT (2006). Speed management. Technical report.

Parry, I. W. and Small, K. A. (2005). Does britain or the united states have the right gasoline tax? *American Economic Review*, 95(4):1276–1289.

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

Rode, P., Burdett, R., Brown, R., Ramos, F., Kitazawa, K., Paccoud, A., and Tesfay, N. (2009). Cities and social equity: inequality, territory and urban form.

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

SP, I. (2017). Retrato da segurança viária - são paulo - 2016.

Vadeby, A. and Forsman, Å. (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 Masterman, C. J. (2017). Income elasticities and global values of a statistical life. *Journal of Benefit-Cost Analysis*, 8(2):226–250.

WHO (2015). *Global status report on road safety 2015*. World Health Organization.

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. 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)

Table 2. Traffic Accidents per year in São Paulo by Location (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 3. Summary Statistics of Trips Simulated Using Google Directions API (July/2017-September/2018)

	All Crawled Trips				Trips over 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
Ratio at Marginais[c]			0.04	0.12			0.22	0.21

Notes: [a] Private vehicle trips reported on the 2012 São Paulo Mobility Household Surey were crawled on Google Directions API using their origin and destination coordinates between July 4, 2016 and September 1, 2017. [b] The speed limit increase in the Marginais was implemented in January 25, 2017. [c] We identify trips over the Marginais by comparing the intercect between the optimal path suggested by OSRM API and a buffer of 200m around the Marginais shapefile. All trips with more than 400m of intercection are defined as running through the Marginais. [d] Travel time and distance are reported by Google Directions API for each query.

Table 4. Summary Statistics of Electronic Driving Tickets issued in São Paulo and Traffic Control Cameras (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 kept by the São Paulo Transit Agency (CET). I 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 equipments are 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 5. Regression Results: The Effects 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 ***	-0.162 ***	-0.176 ***
	(0.032)	(0.035)	(0.040)	(0.035)	(0.037)
2	-0.150 ***	-0.204 ***	-0.217 ***	-0.217 ***	-0.194 ***
	(0.031)	(0.036)	(0.041)	(0.036)	(0.041)
3	-0.108 **	-0.172 ***	-0.179 ***	-0.185 ***	-0.192 ***
	(0.037)	(0.041)	(0.048)	(0.042)	(0.042)
4	-0.112 **	-0.188 ***	-0.188 ***	-0.209 ***	-0.281 ***
	(0.038)	(0.044)	(0.056)	(0.045)	(0.035)
5	-0.221 ***	-0.289 ***	-0.301 ***	-0.305 ***	-0.410 ***
	(0.037)	(0.042)	(0.051)	(0.042)	(0.033)
6	-0.178 ***	-0.259 ***	-0.282 ***	-0.272 ***	-0.363 ***
	(0.037)	(0.041)	(0.050)	(0.041)	(0.037)
7	-0.138 ***	-0.242 ***	-0.292 ***	-0.254 ***	-0.322 ***
	(0.036)	(0.041)	(0.048)	(0.041)	(0.039)
>8	-0.215 ***	-0.313 ***	-0.344 ***	-0.317 ***	-0.405 ***
	(0.030)	(0.036)	(0.046)	(0.036)	(0.033)
Camera on segment					
camera	-0.034	-0.004	0.000	-0.008	0.017
	(0.029)	(0.033)	(0.034)	(0.032)	(0.035)
camera × speed limit reduction	-0.086	-0.106 *	-0.097	-0.099	-0.117 *
	(0.051)	(0.050)	(0.053)	(0.051)	(0.050)
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
Observations	424,356	213,108	105,243	202,758	109,572

Notes: '***' $p < 0.1\%$, '**' $p < 1\%$, '*' $p < 5\%$. 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. Specifications (5)-(6) only include treated segments. Specifications (1)-(5) are fully flexible with respect to monthly fixed effects, however, specification (6) uses a parametric functional for that includes a linear time trend, and citywide covariates (fuel sales and total number of cameras)

Table 6. Regression Results: Additional Changes in Road Accidents on the Marginais Highways

	Dependent variable: number of accidents per segment per month				
	Sample of segments:				
	(1)	(2)	(3)	(4)	(5)
Speed limit reduction					
Marginais highways specific effect	-0.117	-0.111	-0.133	-0.133	-0.101
	(0.097)	(0.098)	(0.107)	(0.097)	(0.100)
Long term effect for all roads	-0.202 ***	-0.300 ***	-0.327 ***	-0.301 ***	-0.398 ***
	(0.029)	(0.035)	(0.041)	(0.035)	(0.032)
Camera on segment					
camera	-0.034	-0.004	0.000	-0.008	0.017
	(0.029)	(0.033)	(0.034)	(0.032)	(0.035)
camera × speed limit reduction	-0.086	-0.106 *	-0.097	-0.099	-0.117 *
	(0.051)	(0.050)	(0.053)	(0.051)	(0.050)
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
Observations	424,356	213,108	105,243	202,758	109,572

Notes: '***' $p < 0.1\%$, '**' $p < 1\%$, '*' $p < 5\%$. [a] SLR = Speed Limit Reduction. Model (1) is an event study based only on treated segments, and the estimation model includes as covariates: total fuel sales per month, total number of cameras, a linear time trend and the presence of camera on the segment, separating the effect between before and after the speed limit change. Model (2) includes a control group of segments with all non-treated avenues and express roads of São Paulo. With the inclusion of a control group, citywide covariates (fuel sales, total cameras and the linear time trend) are dropped and we include month specific fixed effects. Model (3) restricts the control segments to roads that are more than 1600m away from any treated segment. Model (4) restricts treated and control segments from Model (3) to the segments with more than 11 accidents between 2012-2017, which is the mean number of accidents per segment in the period. Finally, Model (5) restricts the segments used in Model (3) using a matching procedure based on the total number of accidents per segment in the pre-period (before July, 2015).

Table 7. Regression Results: Changes in Travel Time After the Marginais Speed Limit Increase of January 25, 2017)

	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. - OffPeak				-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: * $p < 0.05$, ** $p < 0.01$, * $p < 0.001$. 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.

Table 8. Accidents in the Marginais Highways in the Business Days of 2016, Observed and Counterfactual Scenarios

Scenarios[a]	Location		
	All Treated Roads	Marginais Highways	Arterial Roads
Observed in 2016			
Accidents	3,738	352	3,386
Cost (BRL Million)	1,205.2	99.9	1,105.2
Counterfactual scenarios - coefficients from Sample (4)			
No camera expansion			
Accidents	3,838	369	3,469
Cost (BRL Million)	1,236.0	104.8	1,131.1
Policy benefits (BRL Million)	30.8	4.9	25.9
Nor speed limit reductions			
Accidents	5,579	638	4,941
Cost (BRL Million)	1,787.3	178.4	1,608.9
Policy benefits (BRL Million)	582.1	78.5	503.7
Counterfactual scenarios - coefficients from Sample (5)			
No camera expansion			
Accidents	3,858	372	3,486
Cost (BRL Million)	1,242.3	105.8	1,136.5
Policy benefits (BRL Million)	37.2	5.9	31.2
Nor speed limit reductions			
Accidents	6,518	729	5,789
Cost (BRL Million)	2,085.5	202.4	1,883.0
Policy benefits (BRL Million)	880.3	102.5	777.8

Notes: The calculation of policy benefits is based on the counterfactual number of accidents that would be observed in the Marginais Highways during the Business Days of 2016 if the speed limit reduction had not been adopted in 2015. To construct the counterfactual we use the long term policy effects estimated from Sample (3) which matches treatment and control segments based on pre-treatment accidents. The first part of the table shows the number of accidents that were observed in 2016. We calculate the cost of each accident using parameters from IPEA (2016) and the value of statistical life calculated by Viscusi and Masterman (2017) for Brazil. The second part of the table presents the counterfactual scenarios. First we estimate what would happen if the camera expansion had not been adopted simultaneously with the speed limit reductions. Next, we extend the counterfactual to a scenario where speed limit reduction were not adopted in 2015.

Table 9. Total Benefits of Travel Time Gains from the 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 are based on the expansion of household survey trips made by private vehicle to all business days of 2016. Counterfactual scenarios are based on our empirical results of policy impacts. All values are converted to BRL of 2016 by the IBGE IPCA inflation index.

Table 10. Comparing Travel Time Gains Assuming Individual Specific Parameters with Population Average

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 are based on the expansion of household survey trips made by private vehicle to all business days of 2016. Counterfactual scenarios are based on our empirical results of policy impacts. All values are converted to BRL of 2016 by the IBGE IPCA inflation index.

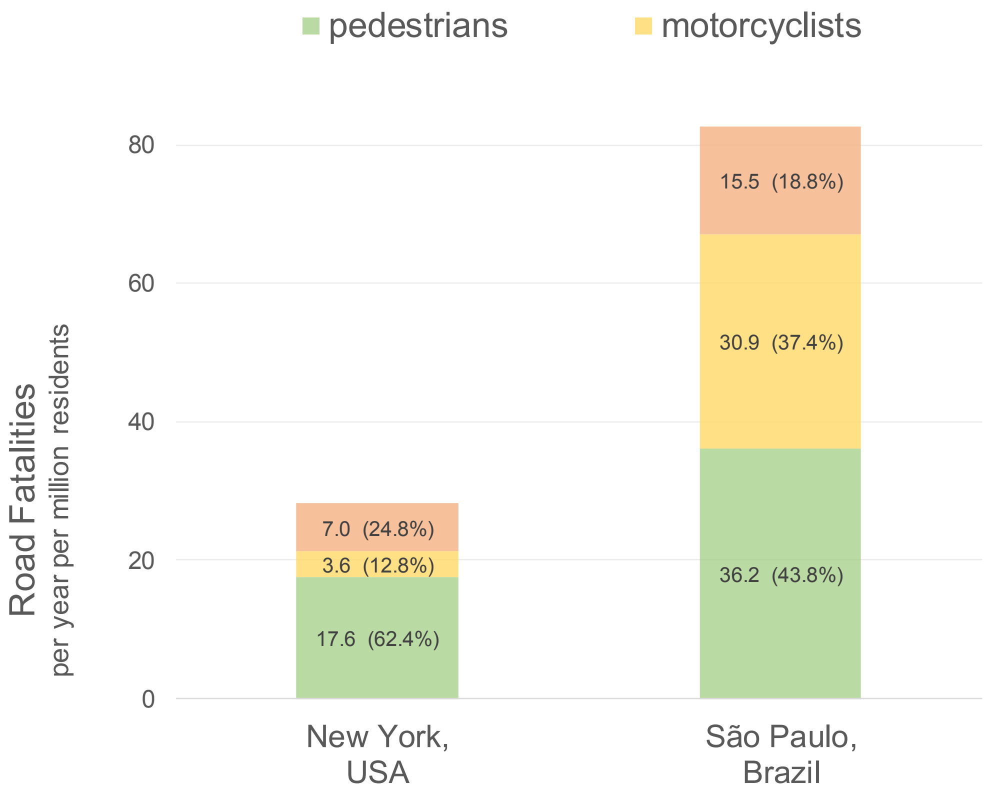
Table 11. Comparison of our Results with van van Benthem (2015)

	Ang, Christensen & Vieira (2018) *Urban highways in São Paulo, Brazil*	Van Benthem (2015) *Western USA freeways*	Ratio *ACV/VB*
Cost-benefit results			
Benefits/costs	1.29	2.21	0.58
Breakeven VSL ratio[a]	0.61	0.50	1.22
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	859	1010	0.85
Fatalities per year	35	24	1.46
Accidents per million VHT	13.7	21.1	0.65
Reduced form estimates			
Travel time	0.057	0.059	0.97
Accidents	0.43	0.14	3.07
Fatalities	0.43	0.44	0.98

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

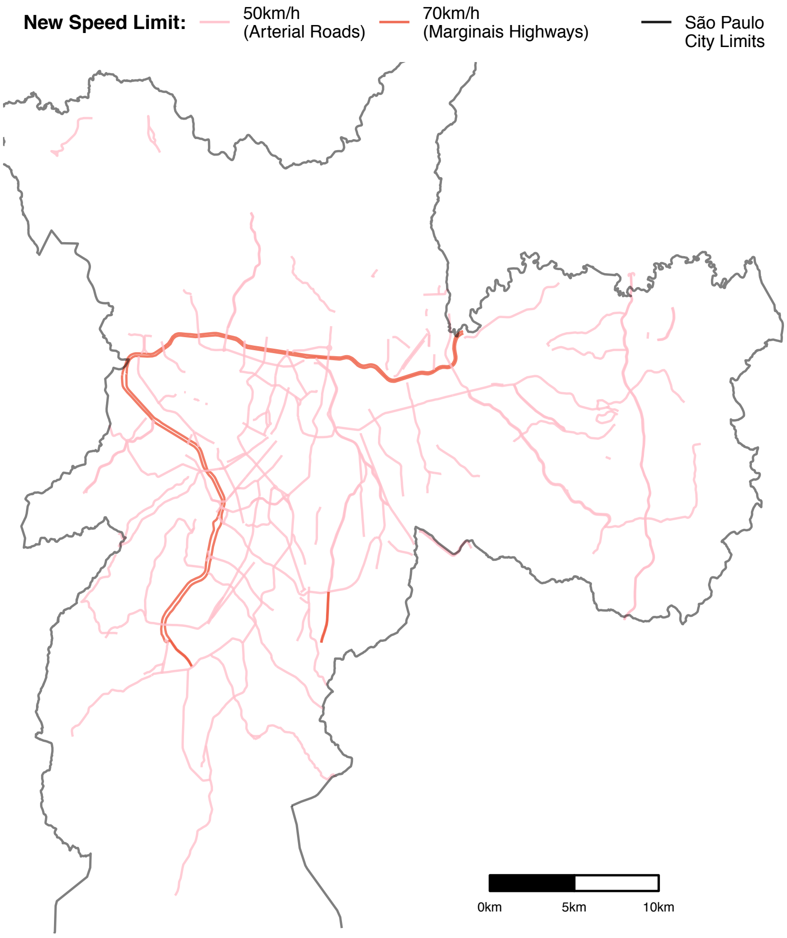
Figures

Figure 1. Road Fatalities per Million Residents in New York, USA, and São Paulo, Brazil



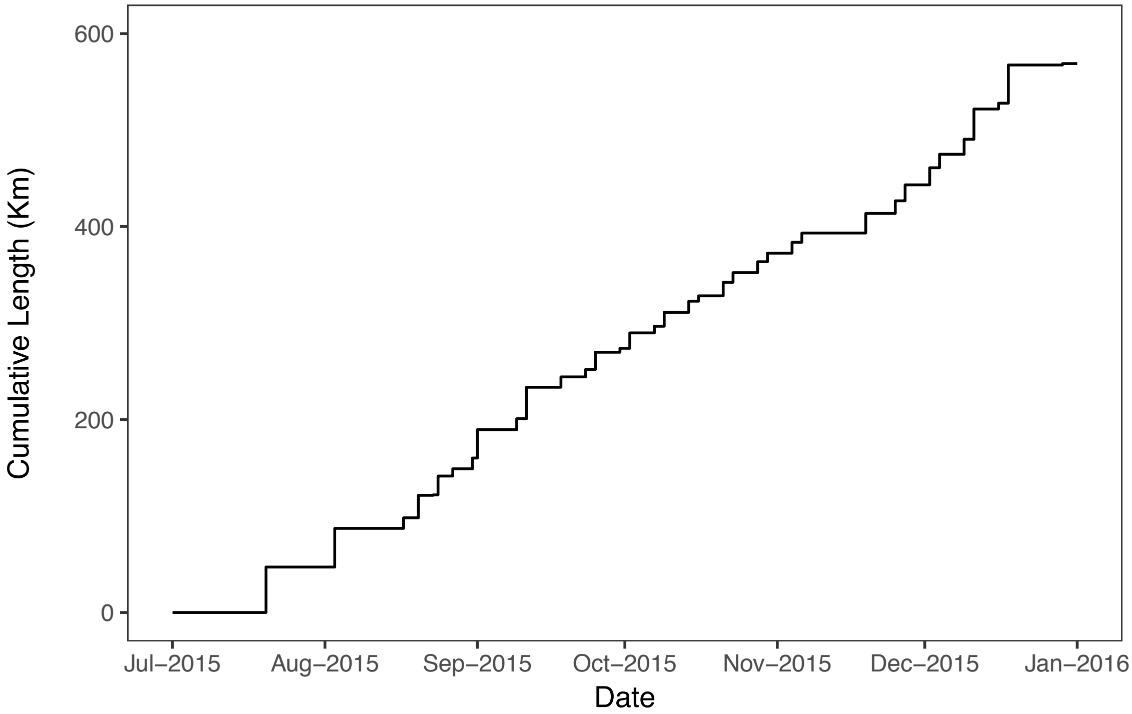
Notes: Data for New York is from the city's Vision Zero Four Year Report (NYC, 2018). Data for São Paulo is from the reports of road accidents compiled by the Transit Agency of São Paulo(CET, 2017)

Figure 2. Road Segments with Speed Limit Reductions in 2015 by New Speed Limit



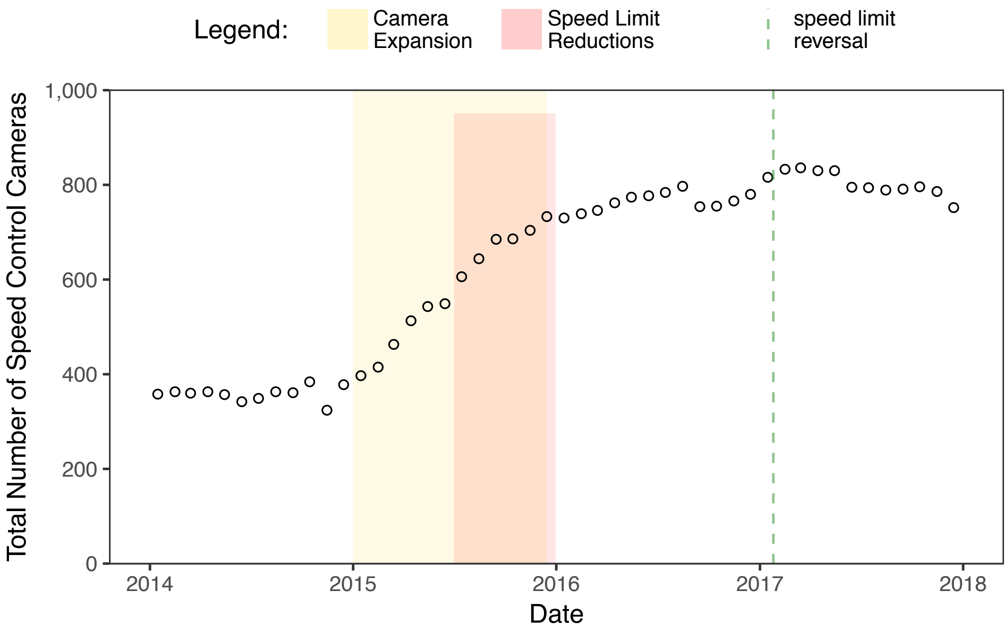
Notes: Information about speed limit changes was scrapped from the newsletters of the São Paulo Transit Agency website (http://www.cetsp.com.br/noticias.aspx). Appendix A provides additional details about this dataset.

Figure 3. Cumulative Length of Road Segments with Speed Limit Reductions (July-December, 2015)



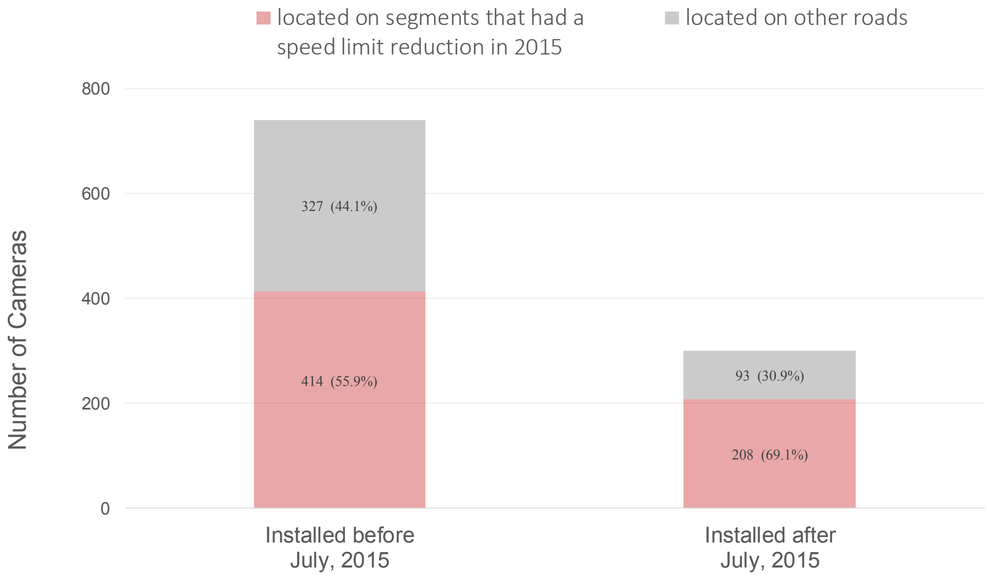
Notes: Information about speed limit changes was scrapped from the newsletters of the São Paulo Transit Agency website (http://www.cetsp.com.br/noticias.aspx). Appendix A provides additional details about this dataset.

Figure 4. Number of Speed Control Cameras in São Paulo by Month (Jan/2014-Dec/2017)



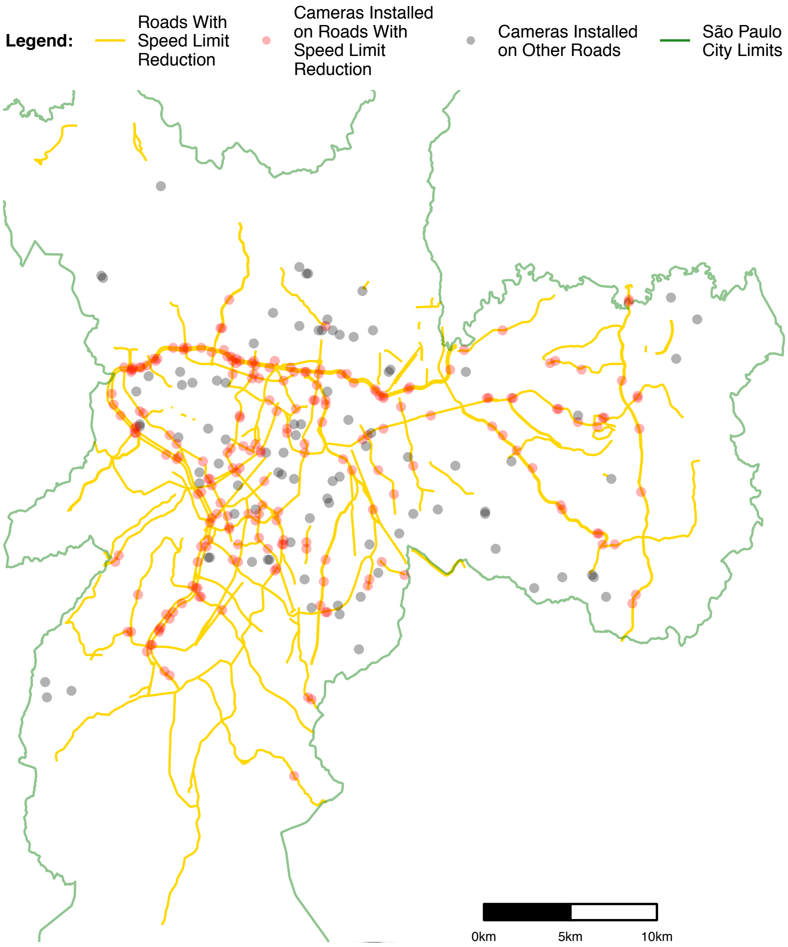
Notes: data about speed monitoring cameras was scraped from the website Painel de Mobilidade Segura (http://mobilidadesegura.prefeitura.sp.gov.br), which is kept by the São Paulo Transit Agency (CET).

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



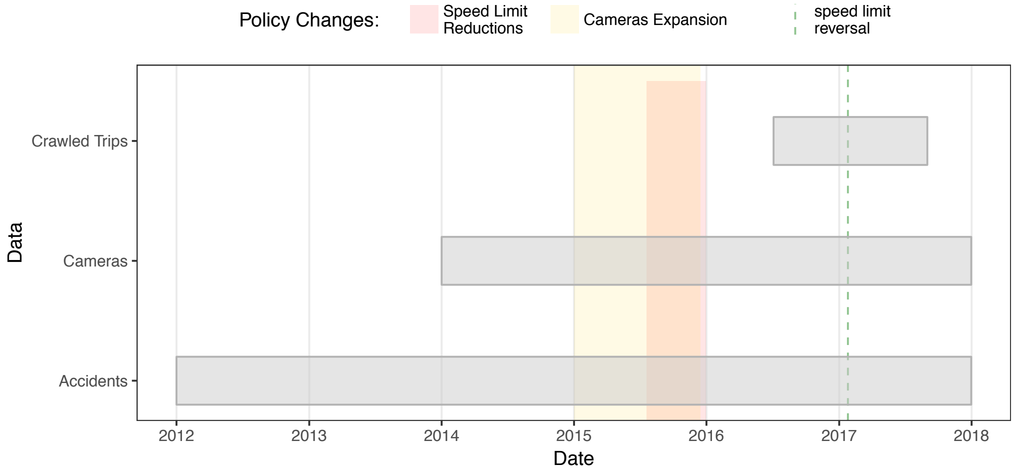
Information about cameras and their location was extracted from the website http://mobilidadesegura.prefeitura.sp.gov.br/ which is maintained by the São Paulo City Hall and compiles information about traffic violations in the city. Road segments are defined as "Treatment Group" if their speed limit was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

Figure 6. Speed Control Cameras Installed after July 20, 2015 and Road Segments with Speed Limit Reductions in the Second Semester of 2015



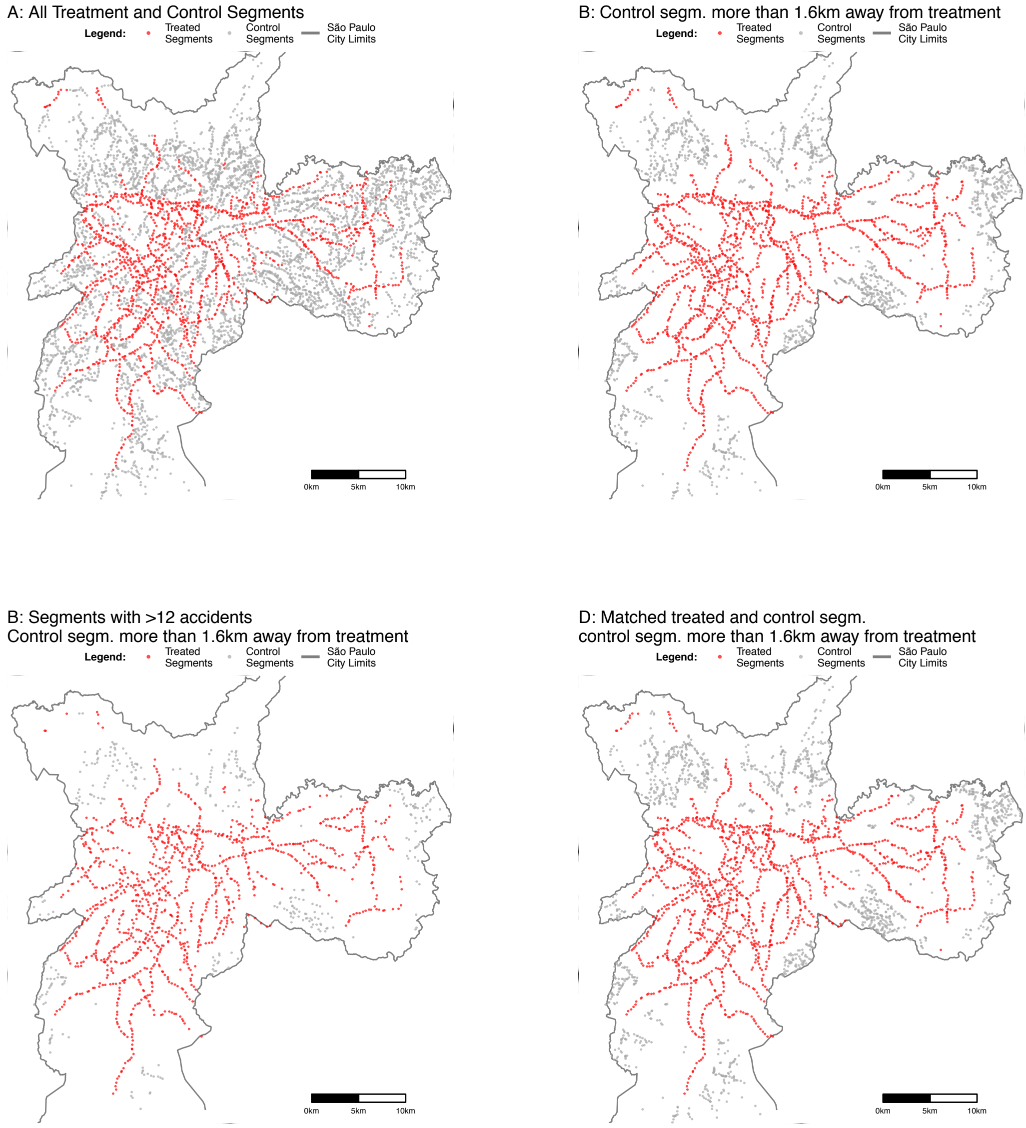
Notes: we identify the date a camera was installed using the minimum date for speeding tickets issued in each location. Data about traffic tickets was scraped from the website Painel de Mobilidade Segura (http://mobilidadesegura.prefeitura.sp.gov.br), which is kept by the São Paulo Transit Agency (CET).

Figure 7. Timeline of Speed Limit Changes and Datasets used in our Analysis



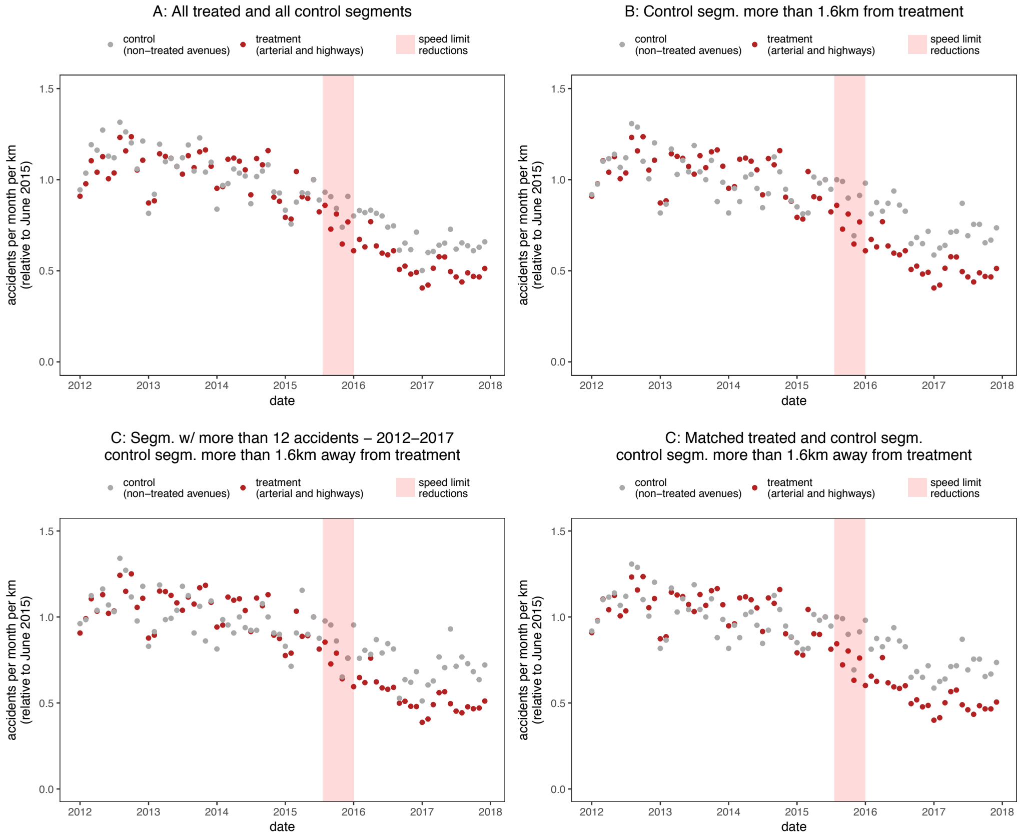
Notes: Crawled Trips refer to representative trips observed on a household travel survey and that were repeatedly simulated using Google Direction's API. data about speed monitoring cameras was scraped from the website Painel de Mobilidade Segura (http://mobilidadesegura.prefeitura.sp.gov.br), which is kept 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.

Figure 8. Map of Treatment and Control Road Segments Used in Our Empirical Models



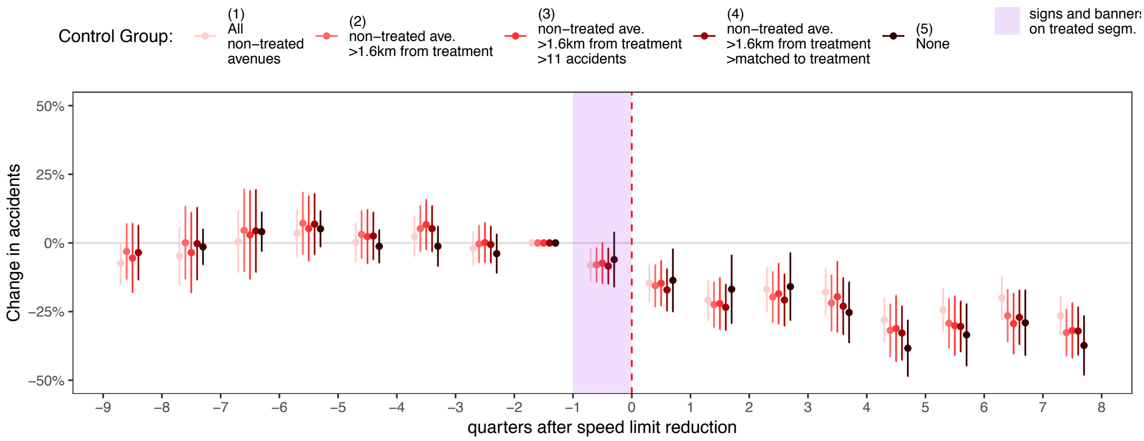
Notes: Treated Segments include all arterial roads and highways where speed limits were reduced in 2015. On Panel A, the control group includes all non-treated avenues and express roads in São Paulo. On Panel B, the control segments are restricted to segments that are more than 1,600m away from any treated road. On 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. Finally, 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 9. Road Accidents on Treated and Control Segments over Time (2012-2017)



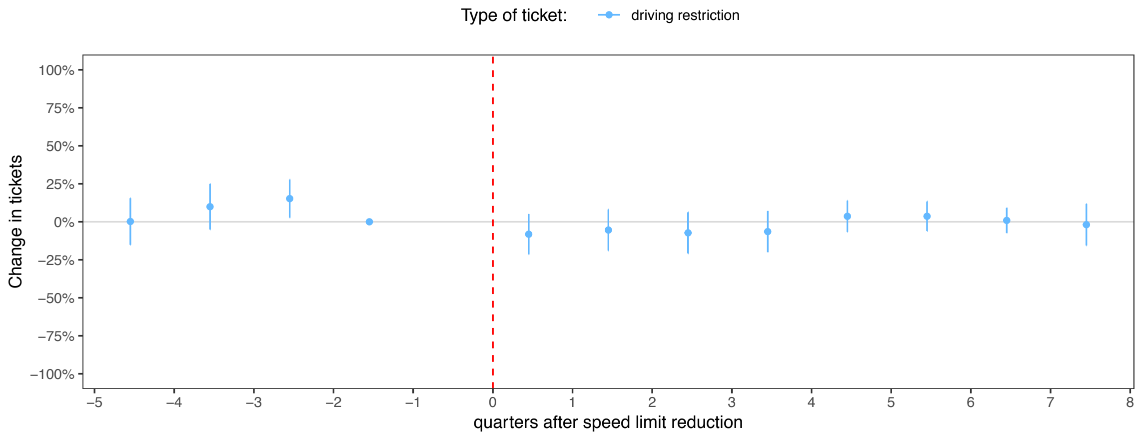
Notes: Each point represents the average number of accidents per km on treatment or control segments in a given calendar month. Treated Segments include all arterial roads and highways where speed limits were reduced in 2015. On Panel A, the control group includes all non-treated avenues and express roads in São Paulo. On Panel B, both the treatment and control groups were reduced to segments with more than 20 accidents in the whole period. On Panel C, the treatment group includes all treatment segments again, however 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 10. Regression Results: The Effects of Speed Limit Reduction and Camera Enforcement on Road Accidents. Leads and Lags of Treatment Date.



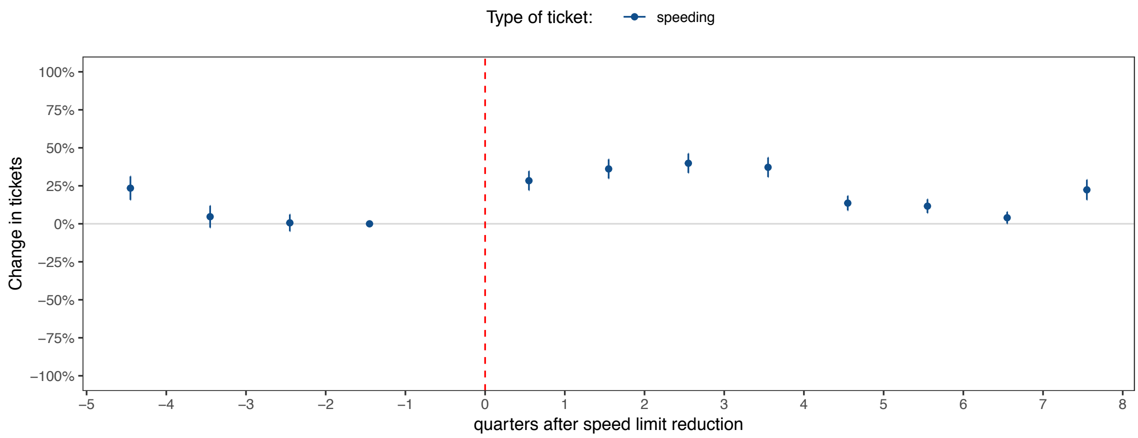
All specifications were estimated using a Poisson regression model with coefficients reported as relative incidence ratios. For instance, a coefficient of 0.1 indicates a 10% larger incidence of accidents. All specifications were estimated using a monthly panel of road segments, however specifications 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. Specifications (5)-(6) only include treated segments. Specifications (1)-(5) are fully flexible with respect to monthly fixed effects, however, specification (6) uses a parametric functional for that includes a linear time trend, and citywide covariates (fuel sales and total number of cameras).

Figure 11. Regression Results: Relative Changes in Driving Restriction Tickets on Treated Segments After Speed Limit Reduction (Proxy for Traffic Volume)



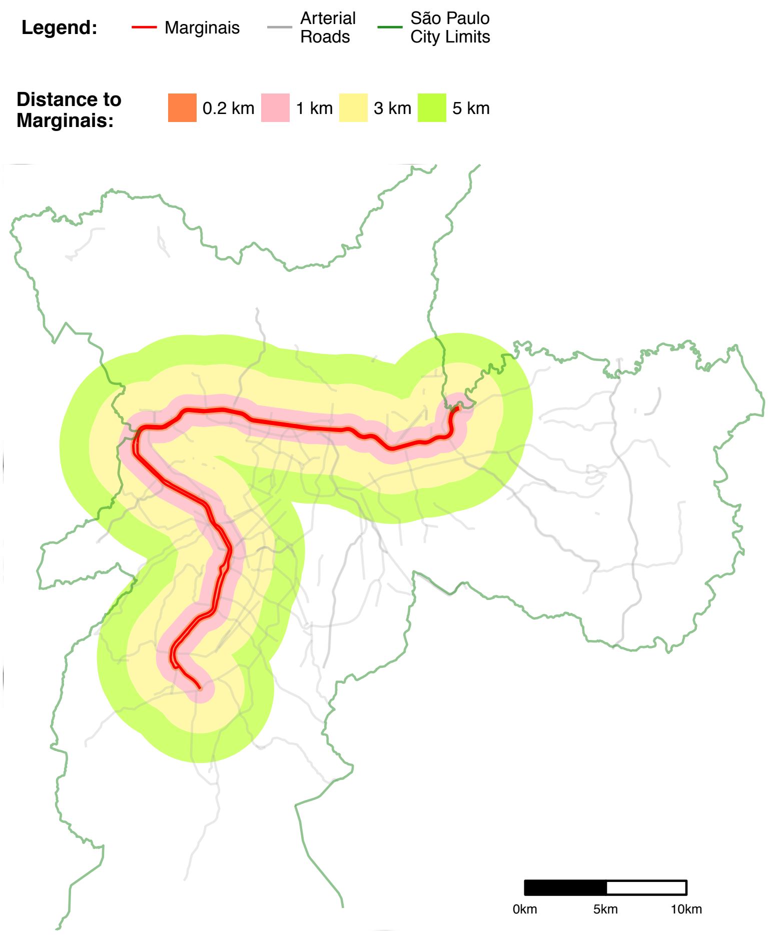
Notes: Segments with cameras are defined as all segments with at least one ticket issued in all months within the period of analysis (2014-2017).

Figure 12. Regression Results: Relative Changes in Speeding Tickets on Treated Segments After Speed Limit Reduction



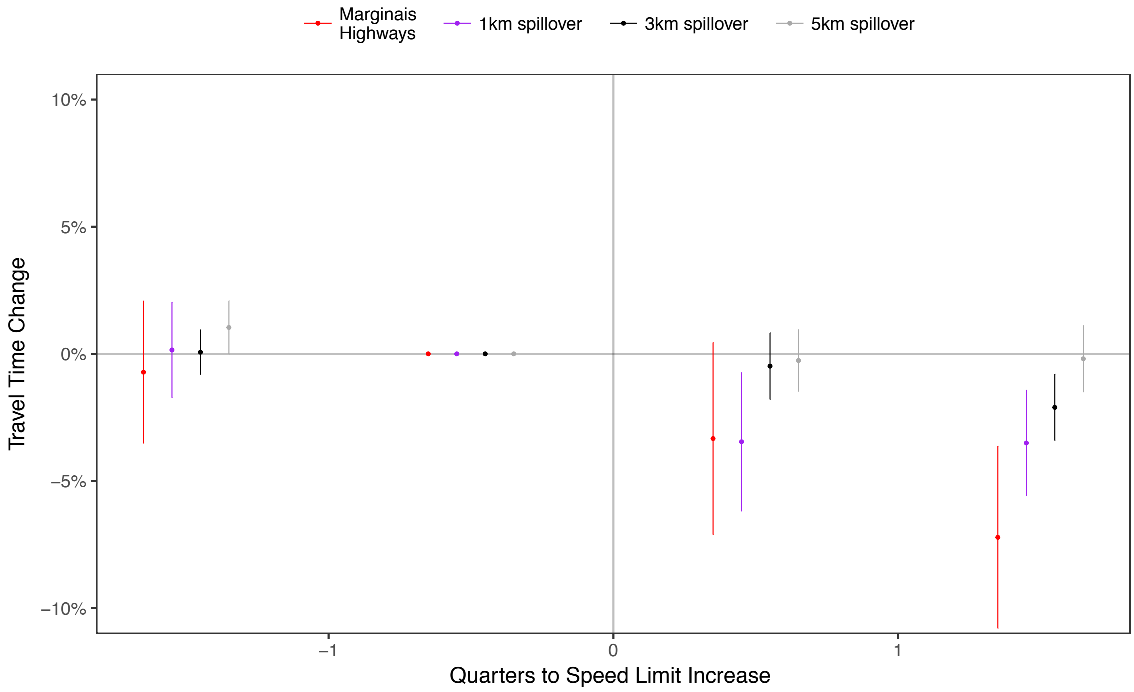
Notes: Segments with cameras are defined as all segments with at least one ticket issued in all months within the period of analysis (2014-2017).

Figure 13. Marginais and Spillover Areas



Notes:

Figure 14. Event-Study Results: Changes in Travel Time After the Speed Limit Increase on Marginais Highways



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

Figure 15. Cost Benefit Results Under Alternative paramenters for VSL

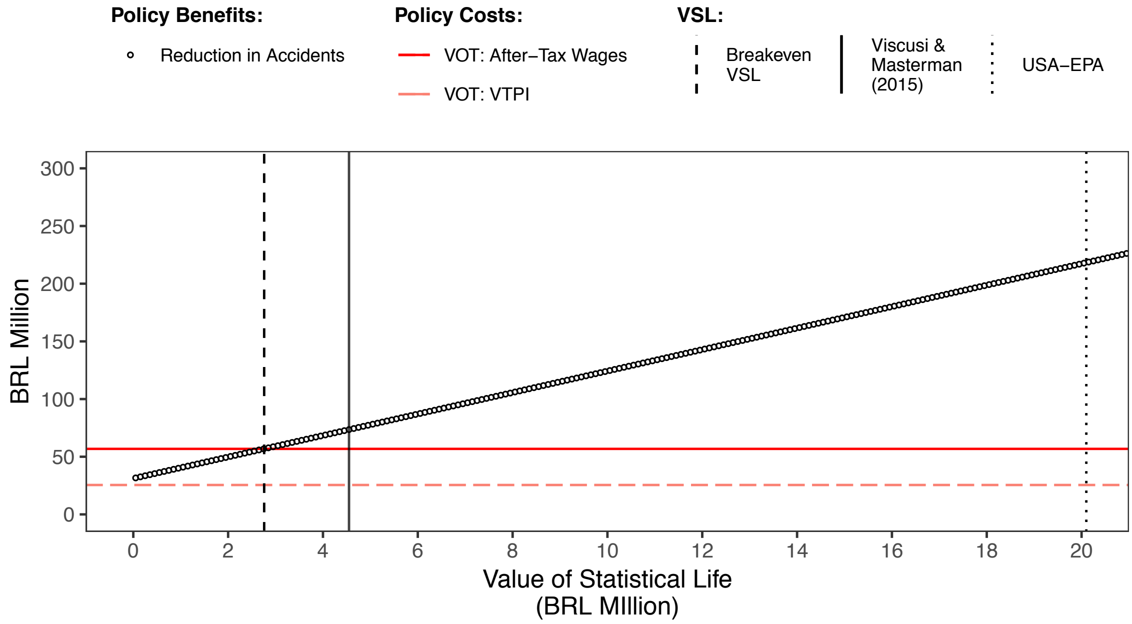
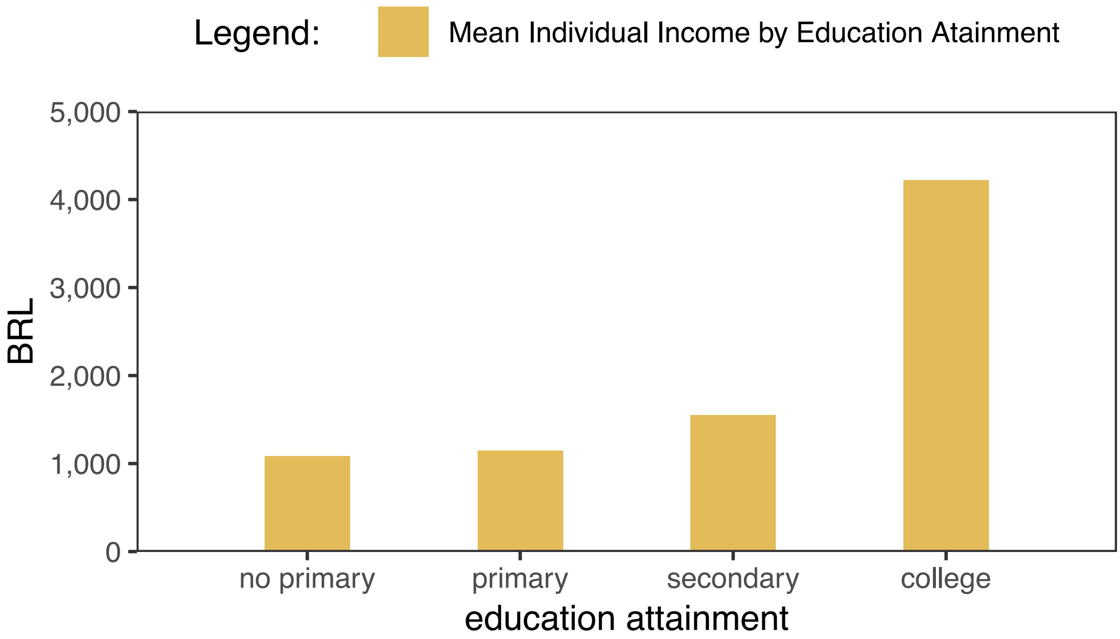
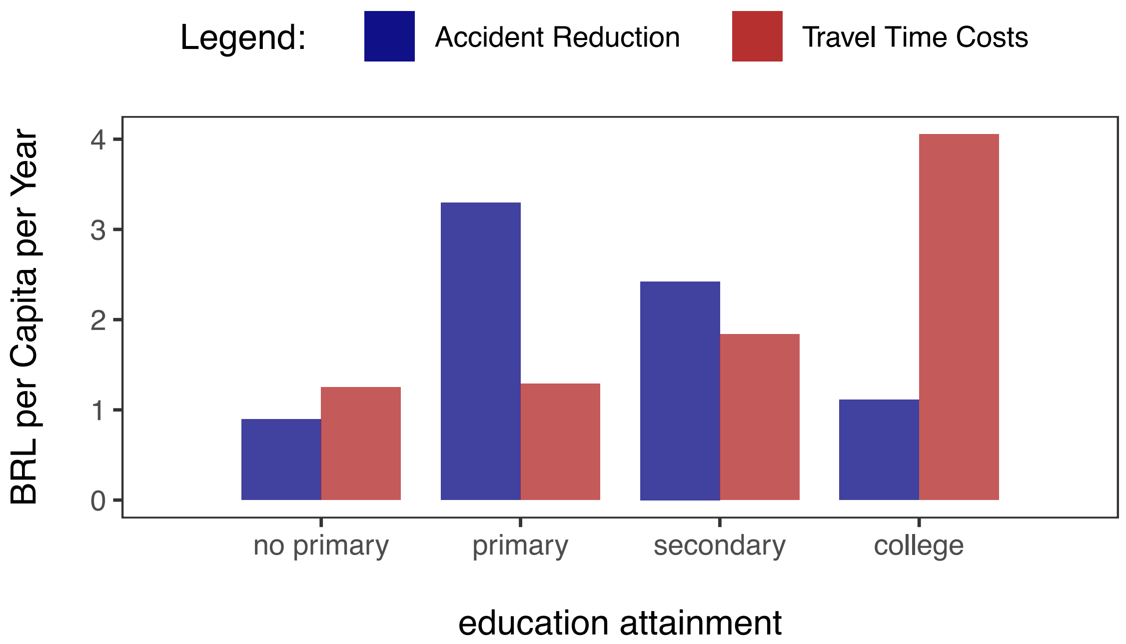


Figure 16. Average Individual Income by Education Attainment



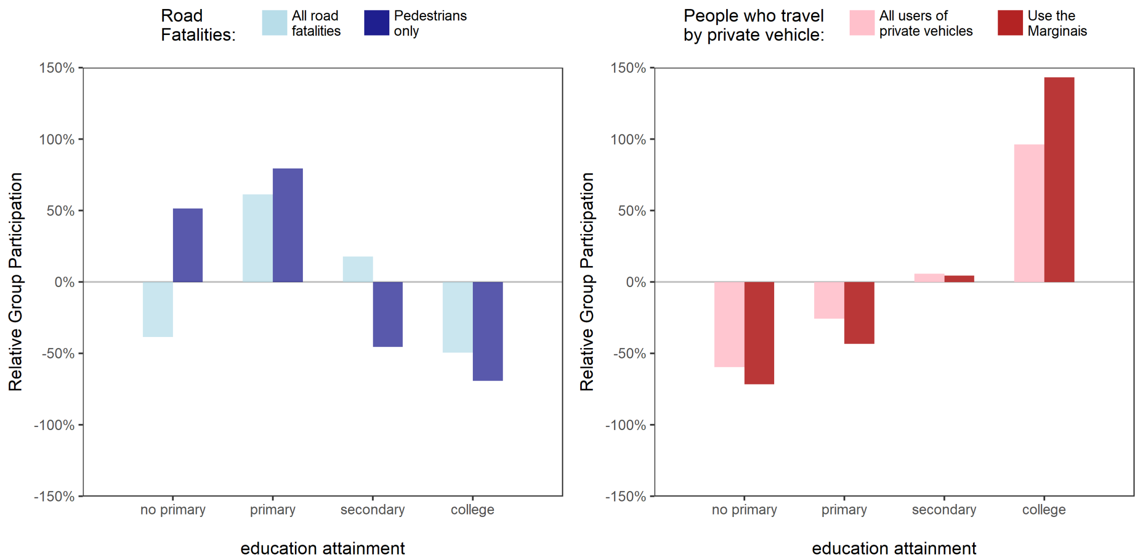
Notes: Based on the sample of adult individuals from the 2012 São Paulo Household Travel Survey.

Figure 17. Per Capita Distribution of Costs and Benefits of Speed Limit Reduction at the Marginais Highways by Education Attainment



Notes: The values for each group were calculated by distributing the additional counterfactual accidents and travel times from the scenario where speed limit changes had not been adopted. The additional accidents were assumed to be distributed equal to the existing ones. Travel time effects were assumed to be proportional to the length of each trip on treated roads. To keep distributions comparable, we assume all individuals have the same VOT and the same VSL which are computed as the average for the total adult population.

Figure 18. Relative Incidence of Traffic Accidents and Relative Use of Private Vehicles by Education Attainment



Notes: The Y-axis indicates the difference between the share of individuals from each group in the population and the share of those groups in each variable. For example, a value of 50% for accidents for the primary education group would indicate that there are 50% more accidents in that group if compared to its participation in the total population.

Appendices

A Speed Change Reports

Figure A.1. Traffic Agency Report from 2015 Indicating Details of an upcoming Speed Limit Reduction

30/07/2015 01:34

Por: CET

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

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 Jacu-Pêssego, na Zona Leste, onde será regulamentada a velocidade máxima de 50 km/h. Atualmente, a velocidade permitida é de 60 e 70 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.

Table A.1. 2015 Speed Limit Change Reports

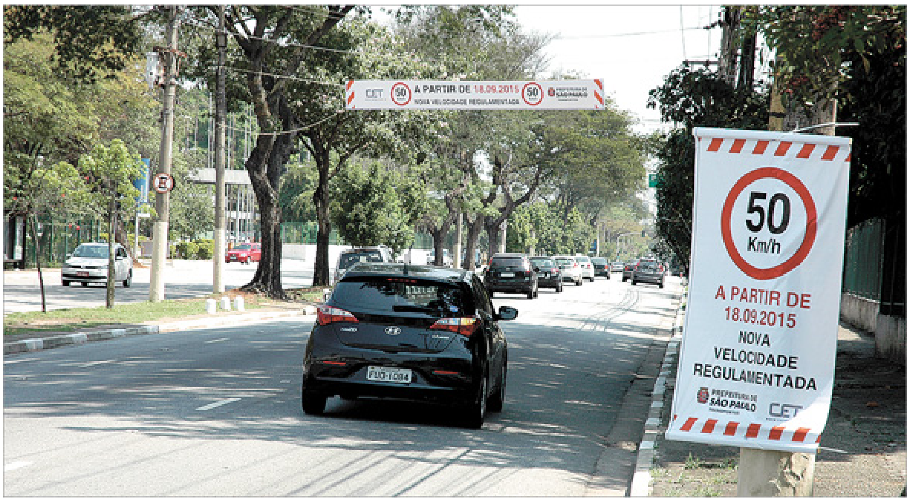
Announcement Date	Speed Limit Change Date	Treated Roads	Link
7/8/2015	7/20/2015	AV MARGINAL DO RIO TIETE, AV MARGINAL DO RIO TIETE	http://www.capital.sp.gov.br/noticia/velocidade-maxima-das-marginais-sera-reduzida-a
7/30/2015	8/3/2015	AV JACU-PESSEGO, AV JACU-PESSEGO	http://www.cetsp.com.br/noticias/2015/07/30/programa-de-protecao-a-vida-cet-implanta-reducao-de-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-

B Speed Change Signs

Figure B.1. Banners indicating an upcoming speed limit reduction in 2015



C Accident Costs Parameters

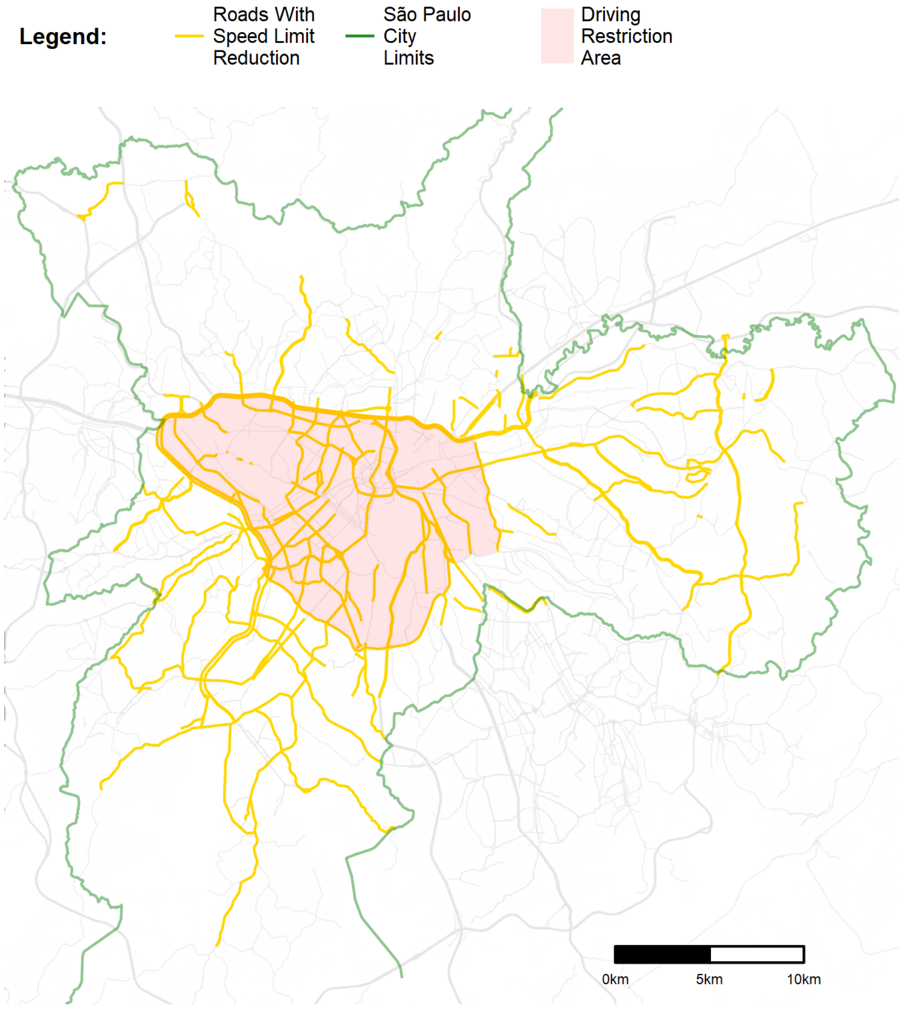
Table C.1. Parameters for Accident Costs Components

	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	14,439	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 comes from Viscusi and Masterman (2017)

D São Paulo Driving Restriction

Figure D.1. Road Segments with Speed Limit Reductions in 2015 and the area of driving restriction in São Paulo.



E Alternative Linear Specification of Accidents Empirical Model

In this appendix, we verify the sensitivity of our main results on the reduction of accidents after the speed limit reductions of 2015. We estimate the policy treatment effect using alternative model specifications and compare their results with our preferred specification included in the body of the paper.

Table E.1. Linear Model: Relative Changes in the Number of Accidents per Segment

	Dependent Variable: number of accidents relative to segment mean				
	(1)	(2)	(3)	(4)	(5)
SLR[a] Long Term Effect	-0.332 ***	-0.206 ***	-0.280 ***	-0.279 ***	-0.294 ***
	(0.049)	(0.035)	(0.047)	(0.050)	(0.045)
Camera - before SLR	0.018	-0.035	-0.007	0.004	-0.018
	(0.027)	(0.023)	(0.028)	(0.026)	(0.026)
Camera - after SLR	-0.055 *	-0.074 **	-0.068 **	-0.043	-0.071 **
	(0.024)	(0.024)	(0.025)	(0.024)	(0.024)
Segment FE	Yes	Yes	Yes	Yes	Yes
Month FE	No	Yes	Yes	Yes	Yes
Citywide Covariates	Yes	No	No	No	No
Observations	112,961	427,745	216,497	107,561	205,634

Notes: '***' $p < 0.1\%$, '**' $p < 1\%$, '*' $p < 5\%$. [a] SLR = Speed Limit Reduction. Model (1) is an event study based only on treated segments, and the estimation model includes as covariates: total fuel sales per month, total number of cameras, a linear time trend and the presence of camera on the segment, separating the effect between before and after the speed limit change. Model (2) includes a control group of segments with all non-treated avenues and express roads of São Paulo. With the inclusion of a control group, citywide covariates (fuel sales, total cameras and the linear time trend) are dropped and we include month specific fixed effects. Model (3) restricts the control segments to roads that are more than 1600m away from any treated segment. Model (4) restricts treated and control segments from Model (3) to the segments with more than 11 accidents between 2012-2017, which is the mean number of accidents per segment in the period. Finally, Model (5) restricts the segments used in Model (3) using a matching procedure based on the total number of accidents per segment in the pre-period (before July, 2015).

Table E.2. Linear Model: Relative Changes in the Number of Accidents per Segment by Road Type

	Dependent Variable: number of accidents relative to segment mean				
	(1)	(2)	(3)	(4)	(5)
SLR[a] Long Term Effect					
Marginais Highways	-0.332 ***	-0.234 *	-0.318 **	-0.277 **	-0.354 ***
	(0.097)	(0.093)	(0.102)	(0.103)	(0.098)
Arterial Roads	-0.331 ***	-0.201 ***	-0.269 ***	-0.265 ***	-0.275 ***
	(0.051)	(0.037)	(0.049)	(0.052)	(0.047)
Camera - before SLR					
Marginais Highways	0.024	0.023	0.024	0.008	0.000
	(0.071)	(0.073)	(0.076)	(0.072)	(0.073)
Arterial Roads	0.016	-0.043	-0.013	0.002	-0.017
	(0.030)	(0.024)	(0.030)	(0.028)	(0.028)
Camera - after SLR					
Marginais Highways	-0.100	-0.102	-0.103	-0.092	-0.088
	(0.064)	(0.065)	(0.068)	(0.066)	(0.065)
Arterial Roads	-0.051 *	-0.068 **	-0.062 *	-0.033	-0.063 *
	(0.026)	(0.026)	(0.027)	(0.026)	(0.026)
Segment FE	Yes	Yes	Yes	Yes	Yes
Month FE	No	Yes	Yes	Yes	Yes
Citywide Covariates	Yes	No	No	No	No
Observations	112,961	427,745	216,497	107,561	205,634

Notes: '***' $p < 0.1\%$, '**' $p < 1\%$, '*' $p < 5\%$. [a] SLR = Speed Limit Reduction. Model (1) is an event study based only on treated segments, and the estimation model includes as covariates: total fuel sales per month, total number of cameras, a linear time trend and the presence of camera on the segment, separating the effect between before and after the speed limit change. Model (2) includes a control group of segments with all non-treated avenues and express roads of São Paulo. With the inclusion of a control group, citywide covariates (fuel sales, total cameras and the linear time trend) are dropped and we include month specific fixed effects. Model (3) restricts the control segments to roads that are more than 1600m away from any treated segment. Model (4) restricts treated and control segments from Model (3) to the segments with more than 11 accidents between 2012-2017, which is the mean number of accidents per segment in the period. Finally, Model (5) restricts the segments used in Model (3) using a matching procedure based on the total number of accidents per segment in the pre-period (before July, 2015).

F Changes in Accidents Effect by Restriction Buffer of the control group

Figure F.1. Regression Results: Average Change in the Number of Speeding Tickets per Camera on Control Segments by Minimum Distance to Treated Roads