IMPACT OF BUS LANES ON THE SPEED OF OTHER VEHICLES IN SÃO PAULO[1,2,3,4]

Rafael Martins de Oliveira[5]
Diogo de Prince[6]
Eduardo Luiz Machado[7]
Veneziano de Castro Araújo[8]

We evaluate the effect of the bus lanes policy in São Paulo between 2010 and 2015. Our focus is the impact of this policy on vehicle speed in other lanes. We use a difference-in-differences model to evaluate the effect of this policy. We find that the average effect of the bus lanes policy is not to affect vehicle speed in other lanes. We also find that the effect is not homogeneous and varies according to the city zone and bus lane operating time (dedicated or intermittent). The estimated effects according to these factors range from 0% to 15%. Regarding policy implications, our result of the bus lane effects associated with its reduced cost supports this urban mobility policy as suitable for large cities in developing countries.

Keywords: urban mobility; bus lane; public policy; difference-in-differences.

IMPACTO DOS CORREDORES DE ÔNIBUS NA VELOCIDADE DE OUTROS VEÍCULOS EM SÃO PAULO

Nós analisamos o efeito da política de faixa de ônibus em São Paulo entre 2010 e 2015. Nosso foco é o impacto dessa política na velocidade dos veículos nas outras faixas. Nós utilizamos o modelo de diferenças em diferenças para avaliar o efeito dessa política. O efeito médio da política de faixa de ônibus é não afetar a velocidade dos veículos nas outras faixas. Nós também encontramos que o efeito não é homogêneo e varia de acordo com a região da cidade e o tipo de faixa de ônibus (dedicada ou intermitente). Os efeitos estimados variam entre 0% e 15%

1. DOI: http://dx.doi.org/10.38116/ppp65art2

2. Acknowledgements: we thank André Chagas, Carlos Roberto Azzoni, Eduardo Haddad, Paula Pereda, Ariaster Baumgratz Chimeli, Nereus and XV Enaber participants for their helpful comments. Rafael Oliveira would like to acknowledge financial support from Higher Education Personnel Improvement Coordination (CAPES).

3. Compliance with ethical standards: on behalf of all authors, the corresponding author states that there is no conflict of interest.

4. Authors' contribution: RO – introduction, conclusion, literature review, technical work and analysis, results interpretation, manuscript writing. DP – introduction, conclusion, literature review, manuscript writing, results interpretation. EM – manuscript writing, literature review. VA – introduction, conclusion, literature review, manuscript writing, results interpretation.

5. Master in economics and development at Federal University of Sao Paulo (Unifesp). E-mail: rafaelmartinsoliveira07@gmail.com. Lattes: http://lattes.cnpq.br/2217950419735180. Orcid: https://orcid.org/0000-0001-8715-0615.

6. Assistant professor in economics at Unifesp. E-mail: diogo.mendonca@unifesp.br. Lattes: http://lattes.cnpq.br/3160691112817642. Orcid: https://orcid.org/0000-0002-4883-2899.

7. Associate professor in economics at Unifesp and associate professor at the Technological Research Institute of the State of Sao Paulo. E-mail: emachado@unifesp.br. Lattes: http://lattes.cnpq.br/8965282450665242. Orcid: https://orcid.org/0000-0002-0209-6822.

8. Assistant professor in economics at Unifesp. E-mail: veneziano.araujo@unifesp.br. Lattes: http://lattes.cnpq.br/2491702233543713. Orcid: https://orcid.org/0000-0003-0994-8327.

considerando tais heterogeneidades. Em relação às implicações da política, nosso resultado do efeito da faixa de ônibus associada com seu custo reduzido apoia a política de mobilidade urbana como adequada para grandes cidades em países em desenvolvimento.

Palavras-chave: mobilidade urbana; faixa de ônibus; política pública; diferenças em diferenças.

IMPACTO DE LOS CARRILES BUS EN LA VELOCIDAD DE OTROS VEHÍCULOS EN SÃO PAULO

Evaluamos el efecto de la política de carriles bus en São Paulo entre 2010 y 2015. Nuestro enfoque es el impacto de esta política en la velocidad de los vehículos en otros carriles. Utilizamos un modelo de diferencias en diferencias para evaluar el efecto de esta política. Encontramos que el efecto promedio de la política de carriles bus es no afectar la velocidad del vehículo en otros carriles. También encontramos que el efecto no es homogéneo y varía según la zona de la ciudad y el tiempo de operación del carril bus (dedicado o intermitente). Los efectos estimados según estos factores oscilan entre el 0% y el 15%. En cuanto a las implicaciones políticas, nuestras observaciones de los efectos de los carriles bus asociados con su costo reducido respaldan esta política de movilidad urbana como adecuada para las grandes ciudades en los países en desarrollo.

Palabras clave: movilidad urbana; carril bus; política pública; diferencias en diferencias.

JEL: C54; O18; R42.

1 INTRODUCTION

Many cities in different countries face rapid motorization growth, leading to increasing congestion and deterioration of traffic conditions (Redman et al., 2013, Rahman et al., 2022). Poor urban mobility conditions reduce the welfare of society and generate an economic cost, with the consequence of increases in freight value and heavy transit, for example (Lucinda et al., 2017; Dourado and Montini, 2014). In this context, the improvement of mobility of people and goods in urban space is an issue that governments should address. Our focus is on a mobility policy that improves the conditions of public transportation in São Paulo. São Paulo is the eighth most populous city in the world, has the fifth highest traffic index in Brazil, and the forth highest traffic index among cities in South America according to the TomTom Traffic Index in 2023.[9]

This high traffic index leads to a discussion of alternatives to public policies. The implementation of bus lanes can change the mobility conditions more quickly and at a lower cost than train or subway systems, for example (Ingvardson and Nielsen, 2018). The implementation of bus lanes in São Paulo increased the average bus speed by 9.13% (Arbex and Cunha, 2016). Basso and Silva (2014) found that this policy generated an increase in the average bus speed from 13 km/h to 27 km/h in London and from 15 km/h to 21 km/h in Santiago.

9. The company TomTom is a manufacturer of automotive GPS and has published the TomTom traffic index since 2012. This index measures the congestion of 390 cities located in 48 countries. The congestion index considers the additional time that a city's drivers spend to move compared to the average time spent for the same trips throughout the year.

Our focus is to analyse the effect of the same policy from a different perspective. We evaluate whether the implementation of bus lanes in São Paulo affected the average speed of vehicles that travel on the same road but outside the bus lane. We consider dedicated bus lane (DBL) and intermittent bus lane (IBL), where IBL is reserved for buses at specific times. Thus, we intend to evaluate the collateral effect of the bus lane policy. Although the main focus of this policy is bus users, the policy also affects users of other transportation modes. In general, the side effects of public transportation policies play a minor role, such as the speed of vehicles in other lanes after the implementation of bus lanes. Side effects of such a policy can be positive – with a road exclusive to public transport users and reordering traffic – or negative – by reducing the traffic space for cars, trucks, and motorcycles, among other vehicles. Therefore, fear of these potential negative side effects could imply under-optimal implementation of the policy and the examination of this point could improve policy quality.

We emphasize that the counterfactual evaluation of the collateral effect of bus lanes in a city with the dimensions of São Paulo has not yet been made, and the literature in this respect is scarce. Basso and Silva (2014) found that the average speed of cars remained constant in London after this policy but fell in Santiago. The results from Arasan and Vedagiri (2010) indicate that vehicle speeds have fallen as a consequence of this policy in Chennai, India. Another point is that Viegas et al. (2007) and Chiabaut and Barcet (2019) are the few studies that analyse the effect of IBL on the speed of the vehicles using empirical data. Most articles that study IBL do simulations. We also evaluate the effect of IBL on the average speed of vehicles traveling outside of the bus lanes using empirical data. Thus, we also contribute to the literature that analyses the effects of IBL on vehicle speed.

To measure the policy effect on the average speed of vehicles traveling outside of the bus lanes, we use the average speed and traffic volume data from a sample of route segments in São Paulo in the period from 2010 to 2015. The database covers 139 roads, 44.6% of which have bus lanes implemented over the analysed period. We adopt the difference-in-differences (DD) method to evaluate how implementation of bus lanes affects the average speed of vehicles outside the lane.

We estimate that bus lanes do not affect the average speed of vehicles traveling outside the bus lanes. This result differs from that of Arasan and Vedagiri (2010) and Paradeda, Kraus Junior and Carlson (2014), who found that bus lanes decrease vehicle speeds outside the lane, but is in agreement with the results of Basso and Silva (2014) for London. Our results are robust even when we consider a traffic policy more related to safety that reduced maximum speed allowed in some roads.

However, analysing the effects by city zone and by operating time of the bus lanes (DBL or IBLs), we found that the effects vary from 0% to +15%. Thus, we conclude that the effect of the bus lanes is heterogeneous throughout the city, changing according to the operating time and city zone. For example, the IBL that is reserved for buses at critical times – the lane is only for buses between 5h and 20h – does not affect the average speed of vehicles outside the bus lane. Bus lanes with other operating times lead to an increase in the average speed of vehicles outside the lane, in agreement with Zhu (2010).

In addition to this introductory section, the next sections review the literature assessing the impacts of urban mobility policies, the implementation of the bus lanes in São Paulo, the database used, the empirical strategy, and the results. Finally, in the last section, we highlight the conclusions of the paper.

2 LITERATURE REVIEW

Several municipalities in the world adopt measures that facilitate bus traffic through the city. Among the most common policies adopted are the construction of bus lanes and bus corridors; that is, the discrimination of one or more lanes totally or partially exclusive to bus traffic. The increase in average bus speed is one of the positive impacts of this policy (Redman et al., 2013).

Basso and Silva (2014) use a transport mode choice model (it includes transport demand elasticities and substitution between private and public transport) to evaluate the effect of bus corridor implementation in the cities of London (between 2004 and 2008) and Santiago (in the year 2001). The authors found that the average speed of buses at peak times increased from 13 km/h to 27 km/h in London and from 15 km/h to 21 km/h in Santiago. On the other hand, the average speed of the cars remained constant in the London roads and fell from 44 km/h to 40 km/h in Santiago on off-peak hours.

Arasan and Vedagiri (2010) obtained similar results for the city of Chennai, India. The authors analysed the flow of vehicles on an important access road to the Chennai Metropolitan Region for one day. Arasan and Vedagiri (2010) simulated a partial equilibrium model and they determined the effect on the average speed if the road had bus lanes or not. The authors note that the implementation of bus lanes would increase the speed of buses to 39.5 km/h (average speed)[10] and the speed of the cars would drop from 39 km/h to 23 km/h for streets of 11 meters wide and from 43 km/h to 38 km/h for streets of 14.5 meters wide.

Additionally, Diab and El-Geneidy (2012) and Gibson et al. (2016) analysed the impact of the implementation of different policies to improve urban mobility,

10. The result of 39.5 km/h obtained by Arasan and Vedagiri (2010) is an average for all different traffic volumes (from 1,000 to 9,500 vehicles/h). Considering the average scenario (5,000 vehicles/h) the effect on the speed developed on the road is 42.4% higher.

including the adoption of bus lanes. Zhu (2010) evaluated the same issue using numerical simulation. According to them, the best practice to improve urban mobility is to combine different policies, including the use of bus lanes (Diab and El-Geneidy, 2012). The location and the type of the lane also impact the results of the policy (Gibson et al., 2016; Zhu, 2010). Zhu (2010) indicates that an IBL is more efficient than a DBL using numerical simulation.[11] Viegas et al. (2007) analyse a six-month experiment in Lisbon, in which IBL increased the speed in 20% of the buses without significantly slowing down general traffic. Chiabaut and Barcet (2019) find that the IBL does not affect traffic conditions in Lyon, but traffic is almost always below saturation conditions.

Gibson et al. (2016) used simulation and found that a median bus lane is appropriate for zones between the city centre and the suburbs, and a kerbside bus lane performs better in central zones, for example. However, the authors are only concerned with bus users when analysing the impact of the bus lane.

Some Brazilian cities[12] already adopt a policy of corridors and bus lanes to soften the problems of urban mobility. Arbex and Cunha (2016) analysed the policy of bus lanes in São Paulo using a mean difference test. Arbex and Cunha (2016) studied the average bus speeds on streets with and without bus lanes in São Paulo over two years. The mean difference test indicated that the bus lanes increase bus speed by 9.13%. Arbex and Cunha (2016) are different from the present study because they assess the effect of the presence of bus lanes on bus speed, while we analyse the effect of the presence of bus lanes on other vehicles except buses.

Paradeda, Kraus Junior and Carlson (2014) studied the effect of bus lanes in Florianopolis. The authors analysed the set of access routes to the island of Florianopolis in 2014 through a model of traffic simulation. Paradeda, Kraus Junior and Carlson (2014) concluded that the implementation of bus lanes in these streets has increased the average speed of buses from approximately 25 km/h to 30 km/h and reduced the average speed of cars. However, if the car fleet were reduced by 20% (because these users would change from cars to buses), it would be possible to cancel the impact of the bus lanes on the average speed of cars.

In some cities, the impact of implementing bus lanes is significant enough to create incentives for people to use the bus over other modes, such as cars. Arasan and Vedagiri (2010) and Moita and Lopes (2016) analysed the probability of

11. Zhu (2010) defines the IBL as a lane that is for buses when the bus is passing in a section of the lane, but after the bus moves on, the lane is open to general traffic.

12. The Brazilian cities that currently have DBLs are São Paulo, Rio de Janeiro, Florianopolis, Curitiba, Salvador, Recife and Goiania. São Paulo is the largest city among these.

drivers switching modes due to the implementation of bus lanes and bus corridors in Chennai and São Paulo, respectively. Moita and Lopes (2016) concluded that the introduction of bus corridors has little effect on people's choice, but the existence of subway stations near the user leads to moderate migration of car users to subways and buses.

We can conclude that few studies in the literature focus on bus lane effects on vehicle speed in other lanes. The literature has more articles analysing IBL with simulation than from collected data. Our contribution tries to fill this gap.

3 BUS LANES POLICY IN SÃO PAULO

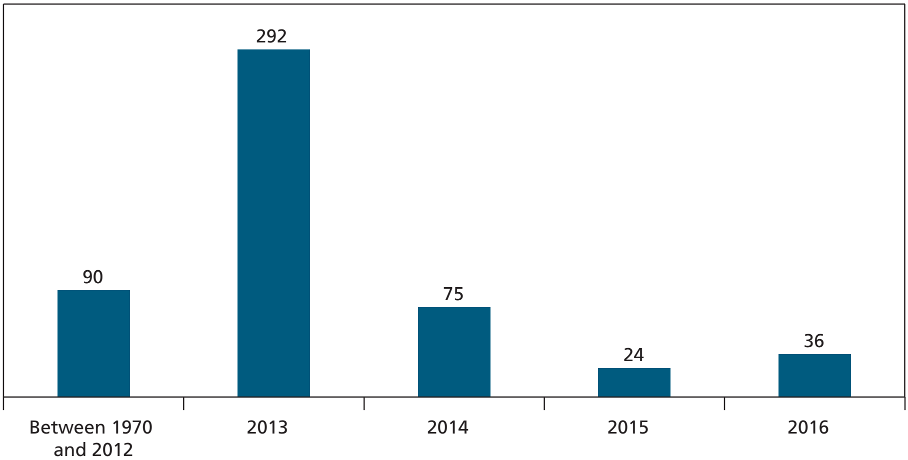
The delimitation of dedicated spaces for bus traffic began in São Paulo in the 1970s with bus lanes and bus corridors. While bus corridors were built gradually over time in the city, the bus lanes only gained importance since 2013 (CET, 2016).[13] There are differences between bus corridors and bus lanes that imply a reduced cost for the latter in São Paulo. Corridors are implemented following roadway adaptation as the construction of the proper lanes for bus traffic and adaptation of the staging points. Meanwhile, bus lanes are installed only with asphalt re-marking, highlighting the perimeter that will be destined for the bus traffic. The traffic of other vehicles in bus lanes is prohibited in São Paulo with one exception: since 2014, a regulation allowed taxis with passengers to use these lanes. Other vehicles can travel in the bus lane for only 100 meters.

As we evaluate the bus lanes, we analyse the years between 2010 and 2015 in which this policy gained relevance and when approximately 446 km of bus lanes were inaugurated. The city had other policies implemented over these years: the reduction of the speed limit in 2014 and 2015, which changed the speed limit on some roads, and taxis allowed to travel in bus lanes in 2014.

Figure 1 shows the number of kilometres of bus lanes inaugurated between 1970 and 2016 in São Paulo. The year 2013 had the highest increase in bus lanes. Figure 1 also indicates that the years subsequent to 2013 were marked by a smaller increase in the number of bus lanes.

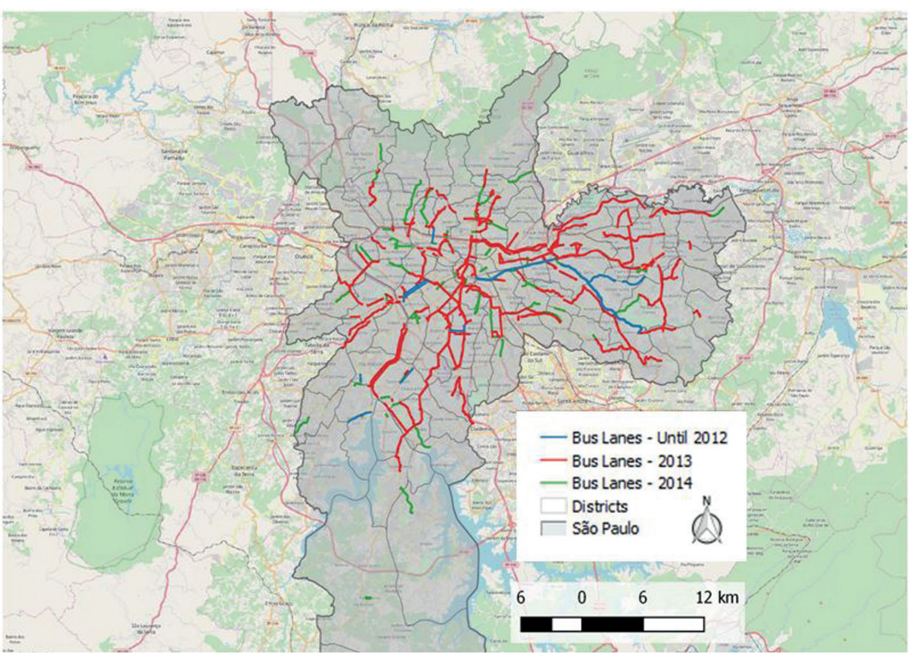
13. Prefeitura de São Paulo. Available at: http://dados.prefeitura.sp.gov.br/dataset/pedidos-de-informacao-protocolados-a-prefeitura-via-e-sic1/resource/c0ad249b-23c9-4a94-b9e9-573ef38a0ea0. Accessed on: Jan. 23, 2023.

FIGURE 1
Number of kilometres of bus lanes inaugurated annually (1970-2016)



Sources: CET (2016) and Prefeitura de São Paulo (available at: http://dados.prefeitura.sp.gov.br/dataset/pedidos-de-informacao-protocolados-a-prefeitura-via-e-sic1/resource/c0ad249b-23c9-4a94-b9e9-573ef38a0ea0; accessed on: Jan. 23, 2023).

MAP 1
Bus lanes designated between 1970 and 2014



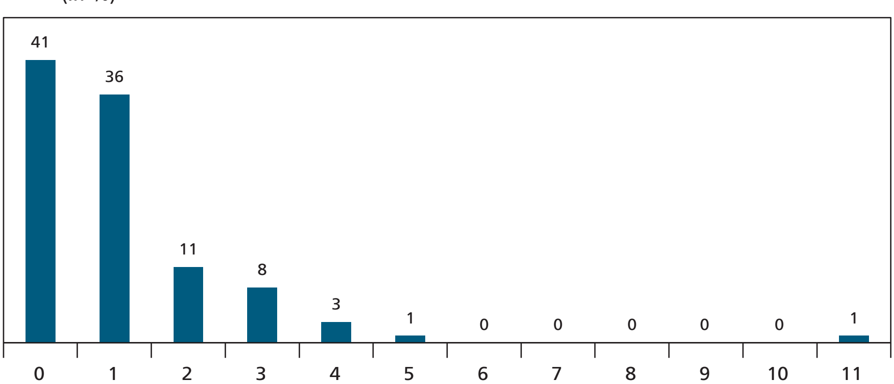
Sources: CET (2016) and Prefeitura de São Paulo (available at: http://dados.prefeitura.sp.gov.br/dataset/pedidos-de-informacao-protocolados-a-prefeitura-via-e-sic1/resource/c0ad249b-23c9-4a94-b9e9-573ef38a0ea0; accessed on: Jan. 23, 2023).
Obs.: Figure whose layout and texts could not be formatted due to the technical characteristics of the original files (Publisher's note).

Map 1 presents the distribution of bus corridors and bus lanes throughout São Paulo. Bus lanes cover a larger area than bus corridors, serving regions that previously did not have corridors, such as the East Zone. In addition, many bus lanes connect users to the subway and train stations, increasing the complementarities between modes.

4 DATABASE AND DESCRIPTIVE STATISTICS

We use the Traffic Engineering Company (CET) and SPTRANS database from 2010 to 2015 for an average of 30 routes each year, containing main roads of the city. CET and SPTRANS measure average speed and number of vehicles – cars, motorcycles, trucks, buses and bicycles – on the route. An official vehicle travels the route in the morning – between 7h and 10h – and in the afternoon – between 17h and 20h – to measure. On average, this official vehicle makes three trips in each direction of the route during the morning and the afternoon to make the measurement. These trips occur in periods that can vary between a few days or weeks. We include Figure 2 which shows the number of weekends that CET and SPTRANS took to measure the three trips in each direction on the same route. This histogram indicates if the measurement interval is longer than one week for example by including one weekend in the measurement interval. 41% of the trips occur in the same week (0 weekends in the measurement interval) and 77% are done in less than two weeks.

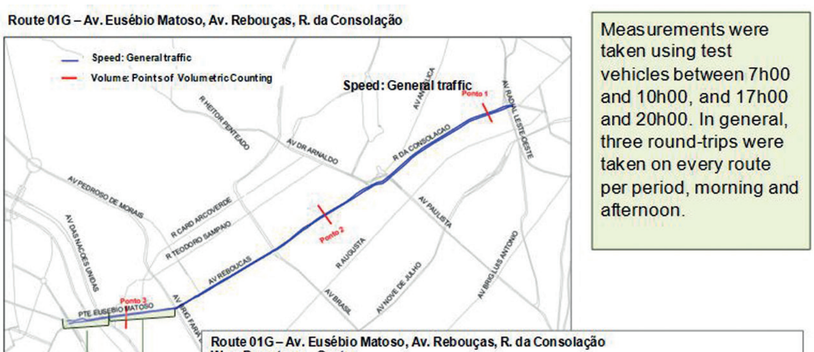
FIGURE 2
Histogram of the number of weekends in the measurement interval
(In %)



Source: CET (2016).

The unit of analysis is route segments belonging to routes monitored by the CET. A route segment can be monitored several times a year, but each time the route segment is selected, it has at least twelve observations, six for each direction. The first observation is collected between 7h and 8h, the second between 8h and 9h, the third between 9h and 10h, the fourth between 17h and 18h, the fifth between 18h and 19h and the sixth between 19h and 20h. Figure 3 illustrates route 01G as an example, with two excerpts that will provide twenty-four observations (two excerpts and six observations, both directions). The route 01G includes nine route segments; each segment has six measurements in both directions (to and from the city centre) and three measuring points for the number of vehicles that travel on the road, which are highlighted in red. For example, the official vehicle leaves from the beginning of Av. Eusébio Matoso – which is on the route – at 7 a.m. towards R. da Consolação according to the illustrated route to measure average speed and number of vehicles in the route segments. Then this vehicle leaves R. da Consolação towards Av. Eusébio Matoso, in this case measuring in both directions of the route. However, this trip by the official vehicle in both directions is generally not done on the same day.

FIGURE 3
Illustrating the unit of measure to obtain average speed and number of vehicles



Route 01G – Av. Eusébio Matoso, Av. Rebouças, R. da Consolação
Way: Downtown - Center
Date: 08/19/2015 to 08/20/2015

Avenue/Road	Begin	End	Dist (m)
Total			6,500
Av. Eusébio Matoso	01. Av. Dr. Vital Brasil	02. Pt. Eusébio Matoso	400
Av. Eusébio Matoso	02. Pt. Eusébio Matoso	03. Av. Pedroso de Morais	1,380
Av. Rebouças	03. Av. Pedroso de Morais	04. Av. Brasil	1,120
Av. Rebouças	04. Av. Brasil	05. R. Oscar Freire	800
Av. Rebouças	05. R. Oscar Freire	06. Av. Paulista	1,050
R. da Consolação	06. Av. Paulista	07. R. Fernando de Albuquerque	500
R. da Consolação	07. R. Fernando de Albuquerque	08. R. Dona Antônia de Queiroz	650
R. da Consolação	08. R. Dona Antônia de Queiroz	09. R. Caio Prado	500
R. da Consolação	09. R. Caio Prado	10. R. Rego Freitas	250

Source: CET (2016).
Obs.: Figure whose layout and texts could not be formatted due to the technical characteristics of the original files (Publisher's note).

Table 1 presents the data available between 2010 and 2015. The number of routes and the share of route segments with bus lanes has increased over the years. CET does not observe all routes every year, generating an unbalanced panel. On the other hand, CET observes some routes twice or more in the same year due to their importance and traffic, which is beneficial for our analysis because we can estimate the effect of changes that have occurred within a year for these routes.

TABLE 1
Route segments and routes analysed by CET and the relevance of bus lanes (2010-2014)

	2010	2011	2012	2013	2014	2015	**Total**
Observations (route segments)	2,202	2,466	2,406	2,166	1,986	1,902	**13,128**
Obs. with bus lane	750	963	1,041	1,098	1,122	1,317	**6,291**
Share (%)	34.1	39.1	43.3	50.7	56.5	69.2	**47.9**
Routes with bus lanes	26	29	29	37	43	47	**66**
Share (%)	35.2	32.6	34.1	46.8	52.4	66.2	**51.2**

Source: CET (2016).

5 EMPIRICAL STRATEGY

We use the DD method to evaluate the impact of a bus lane on the average speed of off-lane vehicles. We make two comparisons to this: between two time periods and between groups involved and not involved in the program (Gertler et al., 2016; Angrist and Pischke, 2008).

The treatment group represents the observations of route segments that at some point in time are treated (route segments that received bus lanes in the period), while the control group includes the observations of route segments that are not treated anytime. According to Angrist and Pischke (2008), the hypothesis adopted is that the time path of the outcome variable for the control group would be the same as the variable for the treated group if there was no intervention. That is, the control group in the post-treatment period should be a true picture of what would happen to the treatment group if it were not treated. In this way, the control and treatment groups must have parallel trends for the method to be valid.

Due to the importance of the hypothesis of parallel trends, we analyse if treatment and control groups have parallel trends before the policy implementation. We aim to verify if there are changes in the trend of the outcome variable in control and treated groups before the treatment. If this variable has a parallel trend in these groups, then we can infer that the variable should continue to move in parallel trends after the implementation of the program (Gertler et al., 2016). Thus, changes in the trajectory of the outcome variable of the treated group in relation to the controls after the program are attributed to the causal effects of the intervention.

Consider the following regression as a simplified form of the DD model

$$Y_{it} = \alpha + \delta X_{it} + \beta D_t + \rho T_{it} + \theta_i + \varepsilon_{it}, \quad (1)$$

in which Y_{it} is the outcome affected by the policy. The subscript t corresponds to the period of time and i to the individual (or observation unit). Vector X_{it} represents the observed characteristics of the individual. T_{it} corresponds to a binary variable that indicates the treatment; that is, it assumes one from the moment of treatment, and zero otherwise. D_t is the year dummy variable. The vector θ_i corresponds to the individual fixed effects. The fixed effect controls the influence of the unobservable characteristics that are constant over time for each individual and ε_{it} is the error term.

In the DD model, fixed effects can be correlated with observed characteristics of individuals, including participation in the program, T_{it}. The DD method controls the self-selection bias by allowing this correlation.

$\hat{\rho}$ is the estimated effect of the policy (conditional to X_{it}) and measures whether the mean of Y for that particular group became different after the intervention. $\hat{\rho}$ captures the average effect of the treatment.

We evaluated if the implementation of bus lanes in São Paulo affected vehicle average speeds in other lanes in the same road using the DD model. The control group corresponds to all route segments without bus lanes between 2010 and 2015 and monitored by CET. The treated group corresponds to route segments with bus lanes at some point between 2010 and 2015, so it does not encompass route segments with bus lanes established before 2010. The estimated equation corresponds to:

$$\Delta Speed_{it} = \beta_0 + \beta_1 BusLane_{it} + \beta_2 Buslane_{it} * MaxSpeedRed_{it} + \beta_3 MaxSpeedRed_{it} + \beta_4 X_{it} + \beta_5 C_{it} + \beta_6 Z_{it} + \beta_7 d_t + \beta_8 m_t + \phi_i + \varepsilon_{it}, \quad (2)$$

in which $\Delta\ Speed_{it}$ is the difference of the average speed in route segment i in year t in logarithmic form. The main explaining variable is $BusLanes_{it}$, a dummy variable equal to 1 if the route segment i in the year t has a bus lane, and 0 otherwise. Between 2010 and 2015, some traffic regulation changed in São Paulo, so we used a set of variables to control the effect of those changes on the average speed. The most important one was the reduction of the speed limit in some roads of the city for safety purposes, which is controlled using the dummy variable $MaxSpeedRed_{it}$. This variable assumes 1 if the route segment i in the year t had suffered a reduction in its speed limit, and 0 otherwise. Taxi regulation also changed. We use the vector X_{it} to control it, which contains the dummy variable $taxipartial_{it}$[14] – assume 1 if it is the period in which the taxi is allowed to circulate in bus lanes with passengers in 18 roads which have bus lanes, and 0 otherwise – and $taxitotal_{it}$[15] –

14. This case occurs during 03/18/2014 and 09/13/2014.
15. This case occurs after 09/13/2014.

assume 1 if it is the period after the taxi is allowed to circulate in the bus lane with passengers in all bus lanes of the city, and 0 otherwise.

The vector C_{it} controls some factors that influence average speed: i) $Period_{it}$[16] is a dummy variable that indicates in which period of the day the observations were collected; ii) $counterflow_{it}$, which is a dummy variable equal to 1 if the observations were in the counter flow, and otherwise 0; iii) $weekend_{it}$ is a dummy variable equal to 1 if the observations were obtained on the weekend, otherwise this dummy is 0; and iv) $Lanes_{it}$ corresponds to the number of lanes in the route segment.

The vector Z_{it} controls route segment traffic: $cars_{it}$, $trucks_{it}$, $motors_{it}$, $partbus_{it}$ and $publbus_{it}$, which indicate the corresponding average share of cars, trucks, motorcycles, particular buses and public buses, respectively.[17] This vector also contains the variable $distrjobs_{it}$, which corresponds to the number of formal workers in each district of the city in year t from the Annual Report on Social Information (Rais). This variable controls the effect of the flow of people going to work on the route segment, which affects the average speed.

The vector d_t has dummy variables for year and month to control seasonality. Additionally, ϕ_i corresponds to the route segment effects.

Since the implementation of the bus lanes occurred partially in parallel to the adoption of other urban mobility policies, we chose to analyse the combined effect of bus lane policy and maximum speed reduction. The model also uses as controls the interaction of the dummy bus lane and allowance for taxi traffic in bus lanes,[18] and the iteration of the speed allowance dummy variable and taxi traffic allowance[19] as controls. Table A.1 in the appendix presents the variable descriptions and sources that we used.

We adopt a panel with fixed effects once the unobserved effects that make the traffic on the route segment slower is correlated with the explanatory variables. In addition, as our observation unit is the route segment, which is part of a route predefined by CET, we assume that the traffic on the route segment is influenced by the traffic condition of the other route segments contained in the same route. Therefore, we consider the existence of an autocorrelation between observations contained in the same route and we chose to correct the errors using clusters for this reason.

16. We use six dummy variables to identify the period of the day the observation was collected: i) between 7h and 8h; ii) between 8h and 9h; iii) between 9h and 10h; iv) between 17h and 18h; v) between 18h and 19h; and vi) between 19h and 20h.

17. Alternatively, we consider the number of cars, trucks, motorcycles, particular buses and public buses as covariates in vector Z_{it}. We obtain similar estimates for the effect of the bus lane policy.

18. The iterations correspond to the multiplication: $BusLane_{it}\ taxipartial_{it}$ and $BusLane_{it}\ taxitotal_{it}$.

19. The iterations correspond to the multiplication: $MaxSpeedRed_{it}\ taxipartial_{it}$ and $MaxSpeedRed_{it}\ taxitotal_{it}$.

In addition, we estimate another model to verify if the impact of the policy is homogeneous all over the city or if there are differences among city zones (north, south, east, west and centre). This model is:

$$\Delta Speed_{it} = \beta_0 + \sum_{j=1}^{5} \beta_j (BusLane_{it} Zone_i) +$$
$$\sum_{j=1}^{5} \delta_j (BusLane_{it} MaxSpeedRed_{it} Zone_i) + \beta_6 MaxSpeedRed_{it} + \beta_7 X_{it} +$$
$$\beta_8 Y_{it} + \beta_9 Z_{it} + \beta_{10} d_t + \beta_{11} m_t + \phi_i + \varepsilon_{it}, \tag{3}$$

in which the vector $Zone_i$ includes $North_i$, $South_i$, $East_i$, $West_i$ and $Center_i$ which are dummy variables equal to 1 if the route segment belongs to each city zone, and 0 otherwise. South, Centre, West, East, and North city zones account for 30%, 25%, 22%, 15% and 8% of bus lanes in the sample, respectively. Therefore, the North and East city zones have a lower bus lane share. This indicates the possibility of heterogeneous effects by city zone, mainly due to the lower presence of bus lanes in the North and East regions.

In addition, we looked at whether the bus lane operating time affects the result of public policy grouped in five categories since some are not full time DBL as some work as IBL:

- IBL – critical time ($Critic_{it}$): bus lane operates between 5h and 20h;
- IBL – rush time morning ($Morning_{it}$): bus lane operates in the morning between 5h and 10h;
- IBL – rush time afternoon ($Afternoon_{it}$): bus lane operates in the afternoon between 17h and 20h;
- IBL – rush time morning and afternoon ($MorningAfternoon_{it}$): bus lane operates in the morning between 5h and 10h and 17h and 20h; and
- DBL – full time ($FullTime_{it}$): bus lane operates all the time.

We use the vector $OperationType_{it}$, which contains the variables $Critic_{it}$, $Morning_{it}$, $Afternoon_{it}$, $MorningAfternoon_{it}$ and $FulltTime_{it}$ to identify the effect of each bus lane operating time. Our data contain 54.1% of observations in the critical period, 1.3% in rush time in the morning, 3.1% in rush time in the afternoon, 22.1% in rush time in the morning and in the afternoon, and 19.4% during the whole day. In this case, we use the following specification:

$$\Delta Speed_{it} = \beta_0 + \sum_{j=1}^{5} \beta_j (BusLane_{it} OperationType_{it}) +$$
$$\sum_{j=1}^{5} \delta_j (BusLane_{it} MaxSpeedRed_{it} OperationType_{it}) +$$
$$\beta_6 MaxSpeedRed_{it} + \beta_7 X_{it} + \beta_8 Y_{it} + \beta_9 Z_{it} + \beta_{10} d_t + \beta_{11} m_t + \phi_i + \varepsilon_{it}. \tag{4}$$

6 RESULTS AND DISCUSSION

The subsection 6.1 presents the main results of bus lane policy and subsection 6.2 the robustness tests.

6.1 Results

Table 2 reports regression results of the model including controls. In column I we report fixed effect results only with controls for year and month (dummy variables) and district employment (in logarithm); in column II we also add a dummy variable for speed reduction, and another for bus lanes that allow taxi traffic and other controls on lane use (vector C_{it}). In column III, we also include variables for the number of lanes in the route segment and volume of vehicles (automobiles, trucks, motorcycles, buses). We use cluster-robust standard error, in which the cluster is per route. We choose a cluster standard errors correction since the route segments contained within the same route possibly are autocorrelated, given that the average speed of each route segment is influenced by the traffic conditions of the next route segment.

TABLE 2
Effect of the bus lanes on the average speed of vehicles that do not travel in the bus lanes

	I	II	III
Bus lane	-0.0289 (0.0508)	0.0455 (0.0353)	0.0388 (0.0491)
1st speed reduction		0.0215 (0.0453)	0.0105 (0.0405)
1st speed reduction * bus lane		-0.0746 (0.0458)	-0.146*** (0.0394)
Test-F for the combinations of the variables "bus lane" and "1st speed red.* bus lane"[1] (Ho: sum of coefficients is zero)		P-value= 0.2240	
Year and month	Yes	Yes	Yes
District employment	Yes	Yes	Yes
Speed reduction	No	Yes	Yes
Taxi traffic allowance	No	Yes	Yes
Route segment controls	No	Yes	Yes
# Lanes and veic. part (%)	No	No	Yes
Cluster-robust	Yes	Yes	Yes
Observations	13,128	13,128	4,140
R^2	0.005	0.116	0.189
Cluster	675	675	179

Authors' elaboration.
Obs.: This table presents results using fixed effects to the variable average speed (natural logarithm). Columns I to III correspond to estimations in which the standard error was corrected by route cluster. Standard error is shown in parenthesis. ***, ** and * represent significance level at 10%, 5% and 1%, respectively.
Note: [1] This test verifies whether the sum of the coefficients of "bus lane" and "1st speed reduction * bus lane" is zero.

The three specifications in table 2 indicate that a bus lane policy does not affect the speed of other vehicles. This result is in agreement with Basso and Silva (2014), who found that there is no effect of bus lane adoption on car speed in London. On the other hand, it is different from that obtained by Arasan and Vedagiri (2010) and Paradeda, Kraus Junior and Carlson (2014), who found that bus lanes decrease the average vehicle speed outside the lane.

In column II, the bus lane with reduction in the maximum speed of the road does not have a statistically significant effect on the average speed of the vehicles outside the bus lane at 5%. When we add the traffic volume control variables, our sample is reduced by 68.5%. If we include such controls, we obtain an estimated coefficient for the exclusive bus lane that is not statistically significant at 5% (column III). Table A.2 of the appendix shows results similar to those in table 2, but using only the sample with vehicle volume data. In all scenarios, the coefficient of the bus lane is not statistically significant at 5%.

In this period, six new subway stations opened in the city, which could affect our estimates of the bus lane effect. We exclude route segments where this new subway stations were created, and we estimate the bus lane effect.[20] We report these estimates in table A.3 of the appendix. The results do not change, showing that they are not affected by the creation of new subway stations.

However, we can refine this result considering the period of the day that the bus lane operates. The variable for the DBL, bus lane operating all day, ($FullTime_{it}$) was dropped because there was no variability over time. We had only 2 cases for this type of bus lane: routes with DBL before 2010 or routes without this type of bus lane throughout the period. That is, there was no creation of full-time bus lanes in the period.

Table 3 presents these results differentiating by bus lane operation time.[21] So the results for these dummy variable coefficients is interpreted as the effect of bus lanes by operation time compared to having no bus lane. In this case, bus lanes generate positive effects on the average speed of other vehicles traveling on the route segment, varying between 10% and 15%, except for the IBL operating during critical hours (from 5h to 20h, which corresponds to 45.3% of bus lanes), in which the effect was -7.39% but not statistically significant at 5%. The afternoon IBL is the one with the highest increase (15%) in the average speed of the vehicles in the other lanes, while the IBL that only operate in the morning or morning and afternoon have increased the average speed of

20. Two subway stations (Butantã and Tamanduateí) are not close to the analysed routes and we do not exclude route segments because they are far from these stations.

21. The results are not affected by the creation of new subway stations, in which we report these estimates in table A.4 of the appendix.

other vehicles by 11.7% and 10%, respectively. The IBL that operates in the critical time does not affect the average speed of the vehicles in the other lanes. Again, when we add the control for volume of vehicles on the route segment, the coefficient of bus lane estimates is no longer statistically significant at 5% in column III.[22]

TABLE 3
Results of bus lane operation type

	I	II	III
Morning	0.163*** (0.0486)	0.117*** (0.0399)	0.0809 (0.0714)
Afternoon	-0.196* (0.114)	0.150* (0.0756)	0.0685 (0.106)
Morning and afternoon	0.0764** (0.0285)	0.100*** (0.0330)	0.0375 (0.0668)
Critic time	-0.0700 (0.0622)	-0.0739 (0.0650)	-0.0156 (0.0903)
Year and month	Yes	Yes	Yes
District employment	No	Yes	Yes
Speed reduction	No	Yes	Yes
Taxi traffic allowance	No	Yes	Yes
Route segment controls	No	Yes	Yes
# Lanes and veic. part (%)	No	No	Yes
Cluster-robust	Yes	Yes	Yes
Observations	13,128	13,128	4,140
R^2	0.005	0.117	0.192
Cluster	675	675	179

Authors' elaboration.
Obs.: This table presents results using fixed effects to the variable average speed (natural logarithm). Columns I to III correspond to estimations in which the standard error was corrected by route cluster. Standard error is shown in parenthesis. ***, ** and * represent significance level at 10%, 5% and 1%, respectively.

Thus, our results indicate that the effect of the bus lane is heterogeneous depending on its an IBL or a DBL, and the time period of operation. For this reason, policymakers must pay attention to this result because the hours of operation of the bus lane seem to affect its efficiency, evidencing that the bus lane with more restricted operation hours (morning, afternoon and morning and afternoon) – that is, in the periods of greater traffic congestion – has a greater effect on other vehicles that travel on the route segment than bus lanes that operate in longer periods of the day (critical period) – and which involve both

22. The explanation is the same as before, where a reduction in the sample leads to a sample bias that excludes those observations in which the effect of the bus lane is relevant. We omitted the table that illustrates this point in order to be more straightforward, but it can be provided by the authors upon reasonable request.

the peak time and the period when the traffic is less intense on the route segment. Chiabaut and Barcet (2019) study indicates that IBLs are more efficient in improving the bus flow and retaining the car flow than DBL.

We also analysed the effects of bus lanes in the different city zones of São Paulo. Table 4 presents the results of the effect of the iteration of bus lane dummy with dummy variables for city zones.[23] We only present the estimates of the coefficients of the bus lane dummy variable to simplify the discussion, although we have included the interaction of the dummy variable of having a bus lane with reducing the speed limit as in table 2.[24]

TABLE 4
Effect of the bus lanes on the average speed of vehicles that do not travel in the bus lanes by city zone

	I	II	III
North	0.0155 (0.0226)	–	–
South	-0.0140 (0.0655)	-0.0487 (0.0704)	-0.00275 (0.116)
East	-0.0588 (0.105)	0.0796 (0.0610)	0.0143 (0.0640)
West	0.134*** (0.0246)	0.112*** (0.0396)	0.146** (0.0537)
Centre	-0.139* (0.0790)	0.0890* (0.0484)	0.0142 (0.0840)
Year and month	Yes	Yes	Yes
District employment	No	Yes	Yes
Speed reduction	No	Yes	Yes
Taxi traffic allowance	No	Yes	Yes
Route segment controls	No	Yes	Yes
# Lanes and veic. part (%)	No	No	Yes
Cluster-robust	Yes	Yes	Yes
Observations	13,128	13,128	4,140
R^2	0.007	0.118	0.192
Cluster	675	675	179

Authors' elaboration.
Obs.: This table presents results using fixed effects to the variable average speed (natural logarithm). Columns I to III correspond to estimations in which the standard error was corrected by route cluster. Standard error is shown in parenthesis. ***, ** and * represent significance level at 10%, 5% and 1%, respectively.

23. Our results are robust to the creation of new subway stations, in which we report these estimates in table A.5 of the appendix.
24. The results are similar to those presented in table A.2 in the appendix but differentiate the bus lane by city zone; these results can be provided by the authors upon reasonable request.

West is the city zone where bus lanes have the highest positive result, increasing the average speed between 11.2% and 14.6%. According to Vieira and Haddad (2015), West has more high speed roads than east and south. Also, they calculate a higher accessibility by private vehicle for the West, which can lead to this bus lane effect of increasing the average speed of other vehicles.

The bus lanes in the East and South zones do not affect the speed of the vehicles in the other lanes. Centre is the city zone where bus lanes do not affect average speed in the less conservative estimate or increase by 8% in the most conservative estimate. This city zone has the best public transportation infrastructure of the city with several subway stations and also has the highest density of jobs (Vieira and Haddad, 2015).

Basically, we can say that the city zone where the bus lane is located affects its result. This result is similar to other studies results regarding heterogeneity of bus operation impacts by city zone such as Nguyen-Phuoc et al. (2018) to Melbourne, Australia. In this way, the city of São Paulo has different spatial patterns of road use. The development of bus lanes in the West zone is more beneficial for vehicles in other lanes than in other regions, while the implementation of the same policy in the South and North of the city has no effect on the average speed of vehicles in other lanes. The mechanisms behind the heterogeneity of the West zone can be deepened with a view to replicating them in other areas or cities.

6.2 Robustness analysis

In this subsection, we consider two robustness exercises. The first is to assess whether the effect we estimated in the previous subsection was not random. Thus, we anticipate the policy erroneously in one year to evaluate if there is an effect associated with the route segments selected to receive treatment. The second test is to analyse whether the average speed observed in the treatment and control groups has the same trend before the route segment is treated, which is an assumption for our results to be valid.

One test is to verify if the previous estimates (tables 2, 3 and 4) that we obtained were not due to random factors, but due to the implementation of the public policy. To test this, we anticipated the treatment by one year. That is, we consider as a treatment the observation of the route segment if the route segment will only receive the bus lane one year from now. We expect to find that the coefficient associated with bus lanes of this anticipation test is not statistically significant, indicating that the effect we obtained in the previous subsection is derived from the policy we analysed and not from factors associated with the route segments selected to receive bus lanes. No bus lane coefficient is statistically significant at 5%

in table 5. That is, we can say that the effects estimated in the previous subsection occur due to the implementation of public policy and not by chance.

TABLE 5
Results of the policy anticipation test

	I	II	III
Bus lane	0.0291 (0.0302)	0.0322 (0.0293)	0.0431 (0.0379)
Year and month	Yes	Yes	Yes
District employment	Yes	Yes	Yes
Speed reduction	No	Yes	Yes
Taxi traffic allowance	No	Yes	Yes
Route segment controls	No	No	Yes
# Lanes and veic. part (%)	No	No	Yes
Cluster-robust	Yes	Yes	Yes
Observations	13.128	13.128	4.140
Cluster	675	675	179

Authors' elaboration.
Obs.: This table presents results using fixed effects to the variable average speed (natural logarithm). Columns I to III correspond to estimations in which the standard error was corrected by route cluster. Standard error is shown in parenthesis. ***, ** and * represent significance level at 10%, 5% and 1%, respectively.

Control and treatment should have the same trend before treatment. Now we evaluate whether the trend in average speed of vehicles in the other lanes is equal between the treatment and control groups before treatment, which is an assumption adopted by the DD model that we use. Our control group is composed of route segments that did not receive bus lanes in the analysed period and the treated groups is route segments that at some point receive a bus lane, but that until that time period did not have a bus lane. The purpose of this test is to verify if the route segment that will receive the bus lane in the future has no other element to explain its current average speed.

To capture this trend, we estimated the model again, only including the dummy variable $TrendPar_{it}$, which assumes a value of 1 if the route segment will have a bus lane and it does not have one yet, and zero if it does not have a bus lane throughout all the analysis period. Table 6 presents the results for the coefficient associated with the $TrendPar$ variable with two specifications (the first one without controlling vehicle flow variables in the lane and the second using these variables as control) with cluster correction of the standard error. The dummy variable in table 6 is not statistically significant at 5% in all scenarios. That is, this result indicates that the hypothesis that the treatment and control follow the same trend is valid.

TABLE 6
Results of the parallel trend test

	I	II
$TrendPar_{it}$	-0.0311 (0.0294)	-0.0352 (0.0488)
Year and month	Yes	Yes
District employment	Yes	Yes
Speed reduction	Yes	Yes
Taxi traffic allowance	Yes	Yes
Route segment controls	Yes	Yes
# Lanes and veic. part (%)	No	Yes
Cluster-robust	Yes	Yes
Observations	6.837	2.400
Cluster	375	115

Authors' elaboration.
Obs.: This table presents results using fixed effects to the variable average speed (natural logarithm). Columns I and II correspond to estimations in which the standard error was corrected by route cluster. Standard error is shown in parenthesis. ***, ** and * represent significance level at 10%, 5% and 1%, respectively.

7 CONCLUSIONS

Public policies are key to improving urban mobility. We evaluate the implementation of bus lanes between the years 2010 and 2015 in São Paulo. We use the DD model to analyse the response of the adoption of the bus lane on the average speed of vehicles in other lanes. Among the main results, we found that the effect of the bus lane policy on the average speed of other vehicles that travel on that route segment stands out. We observed that this effect is not homogeneous throughout the city, varying according to the city zone where the bus lane was implemented (North, South, East, West and Centre) and the operation time that the bus lane operates. This heterogeneous effect according to the city zone is similar to that Nguyen-Phuoc et al. (2018) find for Melbourne. Regarding operation time, bus lane is classified in five subgroups, four IBLs (only functioning in the morning peak time, only in the afternoon peak time, in both peak periods and throughout the daily critical traffic time); and other for DBLs that works all day.

We obtain that bus lanes had no effect on the average speed of other vehicles, which is in agreement with the results of Basso and Silva (2014) from London. On route segments where bus lanes were created and the speed limit was reduced, the average traffic speed on the route segment did not change using the conservative estimate. One explanation for this result is that when transferring the bus from the lanes along with the other vehicles to bus lanes, the bus does not interfere with the traffic of other vehicles with its stops, for example. Although this policy reduces one lane for bus use, the other lanes remain for other vehicles because, according to Basso and Silva (2014), cars also interfere with the bus traffic when there is no bus lane – even the average speed of the bus increases with bus lane. This is in line with the result of Basso and Silva (2014) that the presence of a bus lane increases average speeds of other vehicles during off-peak hours, for example. Bus stop congestion – caused both by buses and passengers boarding – can be a heavy problem at peak times, affecting the traffic of all vehicles on the road according to Basso and Silva (2014). The presence of bus lanes prevents this effect, which may explain our result of this policy not affecting the average speed of other vehicles.

However, when analysing the effects by city zone and by operation time (IBL or DBL), we found that the effects varied between 0% and +15% for route segments where bus lanes were implemented. Thus, it can be concluded that the effect of the bus lane is heterogeneous throughout the city, changing according to the way the route segment is used and the place where it was installed.

The hours of operation of the bus lane seem to affect its efficiency, evidencing that IBL with more restricted operation hours (morning, afternoon and morning and afternoon) – that is, in periods of greater traffic congestion – has a greater effect on other vehicles that travel on the route segment than bus lanes that operate for longer periods of the day (as critical period IBL) – and which involve both the peak time and the period when the traffic is less intense on the route segment. In other words, the bus lane with more restricted operation hours increases the average speed of vehicles in other lanes, in agreement with Zhu (2010).

Our evidence supports bus lane adoption as an urban mobility policy that has a lower cost than train, subway, bus rapid transit or even bus corridors, which may be an option for large cities in developing countries with transportation infrastructure deficits, such as São Paulo.

In addition, this paper adds two important elements to transportation policymakers. First, IBLs have less impact on other vehicles which could be because IBL is implemented on roads where the bus frequency does not necessarily justify a DBL based on Chiabaut and Barcet (2019). Second, we must take into account the differences between city zones. The combination of our results with previous ones suggests that this policy reduces bus travel time, indicating that the adoption of bus lanes in São Paulo improves welfare of bus users without affecting other vehicle users.

Our limitation is not being able to assess whether the adoption of bus lanes leads people to change their travel patterns to taking the bus because of the difference in travel time. However, the results of Moita and Lopes (2016) could indicate that the maintenance of speed or even an increase is not related to consumer's changing transportation mode. As such, our result would be based on lane changing rules that avoid traffic congestion caused by buses on cars. A final consideration is that we did not evaluate the optimal size of bus lanes coverage in the city and its interrelation with other transportation modes.

Another limitation is that we do not have information on traffic speed on other roads nearby. As a consequence, these data do not allow measuring whether there are network/spillover effects to on nearby roads. We cannot analyse whether the implementation of a bus lane on a given road will generate additional traffic to adjacent roads.

REFERENCES

ANGRIST, J. D.; PISCHKE, J. S. **Mostly harmless econometrics**: an empiricist's companion. Princeton: Princeton University Press, 2008.

ARASAN, V. T.; VEDAGIRI, P. Study of the impact of exclusive bus lane under highly heterogeneous traffic condition. **Public Transport**, v, 2, n. 1-2, p. 135-155, 2010. Retrieved from: https://doi.org/10.1007/s12469-010-0021-x.

ARBEX, R. O.; CUNHA, C. B. da. Avaliação das mudanças nas velocidades das linhas de ônibus da cidade de São Paulo após a implantação de faixas exclusivas através da análise de dados de GPS. **TRANSPORTES**, v. 24, n. 4, p. 21-31, 2016.

BASSO, L. J.; SILVA, H. E. Efficiency and substitutability of transit subsidies and other urban transport policies. **American Economic Journal: Economic Policy**, v. 6, n. 4, p. 1-33, 2014. Retrieved from: https://doi.org/10.1257/pol.6.4.1.

CET – COMPANHIA DE ENGENHARIA DE TRÁFEGO. **Pesquisa de monitoração da mobilidade**: mobilidade no sistema viário principal – volume e velocidade 2015. São Paulo: CET, set. 2016. Retrieved from: http://www.cetsp.com.br/sobre-a-cet/relatorios-corporativos.aspx.

CHIABAUT, N.; BARCET, A. Demonstration and evaluation of an intermittent bus lane strategy. **Public Transport**, v. 11, n. 3, p. 443-456, 2019.

DIAB, E. I.; EL-GENEIDY, A. M. Understanding the impacts of a combination of service improvement strategies on bus running time and passenger's perception. **Transportation Research Part A: Policy and Practice**, v, 46, n. 3, p. 614-625, 2012. Retrieved from: http://dx.doi.org/10.1016/j.tra.2011.11.013.

DOURADO, R. C. M. de M.; MONTINI, A. de Á. Modelos de previsão de trânsito: uma contribuição para a gestão pública do tráfego na cidade de São Paulo. **FACEF Pesquisa: Desenvolvimento e Gestão**, v. 17, n. 3, p. 305-321, 2014.

GERTLER, P. J. et al. **Impact evaluation in practice**. 1st ed. Washington: IBD; World Bank, 2016.

GIBSON, J. et al. Estimating the bus user time benefits of implementing a median busway: methodology and case study. **Transportation Research Part A: Policy and Practice**, v. 84, p. 72-82, 2016. Retrieved from: https://doi.org/10.1016/j.tra.2015.07.011.

INGVARDSON, J. B.; NIELSEN, O. A. Effects of new bus and rail rapid transit systems: an international review. **Transport Reviews**, v. 38, n. 1, p. 96-116, 2018.

LUCINDA, C. R. et al. The economics of sub-optimal policies for traffic congestion. **Journal of Transport Economics and Policy**, v. 51, n. 4, p. 225-248, 2017.

MOITA, R. M. S.; LOPES, C. E. M. Demanda por meios de transporte na Grande São Paulo: uma análise de políticas públicas. **Pesquisa e Planejamento Econômico**, Rio de Janeiro, v. 46, n. 2, p. 125-149, 2016.

NGUYEN-PHUOC, D. Q. et al. Modelling the net traffic congestion impact of bus operations in Melbourne. **Transportation Research Part A: Policy and Practice**, v. 117, p. 1-12, 2018.

PARADEDA, D. B.; KRAUS JUNIOR, W.; CARLSON, R. C. Implantação de faixas exclusivas para ônibus: efeito da troca modal no tráfego de automóveis. In: CONGRESSO DE PESQUISA E ENSINO EM TRANSPORTES, 28., 2014, Curitiba, Paraná. **Proceedings**… 2014.

RAHMAN, M. M. et al. Traffic congestion and its urban scale factors: empirical evidence from American urban areas. **International Journal of Sustainable Transportation**, v. 16, n. 5, p. 406-421, 2022.

REDMAN, L. et al. Quality attributes of public transport that attract car users: a research review. **Transport Policy**, v. 25, 119-127, 2013.

VIEGAS, J. M. et al. Intermittent bus lane system: demonstration in Lisbon, Portugal. In: TRANSPORTATION RESEARCH BOARD ANNUAL MEETING, 86., 2007, Washington DC, United States. **Proceedings**… 2017.

VIEIRA, R. S.; HADDAD, E. A. An accessibility index for the Metropolitan Region of São Paulo. In: KOURTIT, K.; NIJKAMP, P.; STOUGH, R. R. (Ed.). **The rise of the city**: spatial dynamics in the urban century. 1st ed. Cheltenham: Edward Elgar Publishing, 2015. p. 242-258.

ZHU, H. B. Numerical study of urban traffic flow with dedicated bus lane and intermittent bus lane. **Physica A: Statistical Mechanics and its Applications**, v. 389, n. 16, p. 3134-3139, 2010. Retrieved from: https://doi.org/10.1016/j.physa.2010.03.040.

COMPLEMENTARY BIBLIOGRAPHY

FOGUEL, M. N. Diferenças em diferenças. In: MENEZES FILHO, N. (Org.). **Avaliação econômica de projetos sociais**. 1st ed. São Paulo: Dinâmica Gráfica e Editora, 2012. p. 69-83.

APPENDIX A

TABLE A.1
Variable description and data source

Vector	Variable	Description	Source
	Speed	Average speed (log form)	Traffic Engineering Company (CET)
	BusLane	Dummy equals to 1 if it has bus Lane	São Paulo City Traffic Department S.A. (SPTRANS), São Paulo Obras S.A. (SPOBRAS)
	MaxSpeedRed	Dummy equals to 1 if it has its speed limit changed	CET, SPTRANS
$Zone_i$	North, South, East, West, Center	Dummy equals to 1 if it is located in each region	CET, Portal de Mapas Oficial da Cidade de São Paulo (Geosampa)
$OperationType_{it}$	CriticT, Morning, Afternoon, MorningAfternoon, Integral	Dummy equals to 1 if it has a bus lane in each type of operation, respectively	CET, SPTRANS
X_{it}	taxipartial	Dummy equals to 1 if it has a bus lane which is allowed to taxi traffic with passengers since 03/18/2014	Secretaria Municipal de Mobilidade e Transportes (SMT)
X_{it}	taxitotal	Dummy equals to 1 if it has a bus lane which is allowed to taxi traffic with passengers since 09/13/2014	SMT
C_{it}	counterflow	Dummy equals to 1 if it is in counter flow	CET
C_{it}	weekend	Dummy equals to 1 if the data is collected during weekend	CET
C_{it}	DM1, DM2, DM3	Dummy equals to 1 if it is collected in the morning between 7h and 8h, 8h and 9h or 9h and 10h, respectively	CET
C_{it}	DT1, DT2, DT3	Dummy equals to 1 if it is collected in the afternoon between 17h and 18h, 18h and 19h or 19h and 20h, respectively	CET
C_{it}	Lanes	Number of lanes in the route segment	CET
Z_{it}	cars, trucks, moto, partbus, publbus	% of cars, trucks, motorcycles, particular buses, and public buses in the route segment, respectively	CET
Z_{it}	publbus	% of public buses in the route segment	CET
Z_{it}	Distrjobs	Jobs in the district in which the route segment *i* is located	Annual Report on Social Information (Rais)
d_t	M	Dummy for months	–
d_t	yy	Dummy for year	–

Authors' elaboration.

TABLE A.2
Effect of the bus lanes on the average speed of vehicles that do not travel in the bus lanes, considering only the observation with volume of vehicles

	I	II	III
Bus lane	-0.0168 (0.0538)	0.0401 (0.0483)	0.0388 (0.0491)
1st speed reduction		-0.0280 (0.0872)	0.0105 (0.0405)
1st speed reduction * bus lane		-0.0566 (0.0825)	-0.146*** (0.0394)
Year and month	Yes	Yes	Yes
District employment	Yes	Yes	Yes
Speed reduction	Não	Yes	Yes
Taxi traffic allowance	No	Yes	Yes
Route segment controls	No	Yes	Yes
# Lanes and veic. part (%)	No	No	Yes
Cluster-robust	Yes	Yes	Yes
Observations	4,962	4,962	4,140
R^2	0.005	0.123	0.189
Cluster	261	261	179

Authors' elaboration.
Obs.: Columns I to III correspond to estimations in which the standard error was corrected by route cluster. Standard error is shown in parenthesis. ***, ** and * represent significance level at 10%, 5% and 1%, respectively.

TABLE A.3
Effect of the bus lanes on the average speed of vehicles that do not travel in the bus lanes (excluding route segments with the opening of new subway stations in the period)

	I	II	III
Bus lane	-0.0301 (0.0505)	0.0460 (0.0349)	0.0421 (0.0491)
1st speed reduction		0.0202 (0.0471)	0.0162 (0.0409)
1st speed reduction * bus lane		-0.0748 (0.0464)	-0.147*** (0.0401)
Test-F for the combinations of the variables "bus lane" and "1st speed red.* bus lane"[1] (Ho: sum of coefficients is zero)		P-value= 0.6622	
Year and month	Yes	Yes	Yes
District employment	Yes	Yes	Yes
Speed reduction	No	Yes	Yes

(Continues)

(Continued)

	I	II	III
Taxi traffic allowance	No	Yes	Yes
Route segment controls	No	Yes	Yes
# Lanes and veic. part (%)	No	No	Yes
Cluster-robust	Yes	Yes	Yes
Observations	12,924	12,924	4,074
R^2	0.006	0.122	0.192
Cluster	669	669	177

Authors' elaboration.
Obs.: This table presents results using fixed effects to the variable average speed (natural logarithm). We use standard error corrected by route cluster. Standard error is shown in parenthesis. ***, ** and * represent significance level at 10%, 5% and 1%, respectively.
Note: [1] This test verifies whether the sum of the coefficients of "bus lane" and "1st speed reduction * bus lane" is zero.

TABLE A.4
Results of adopting controls according to the bus lane operation type (excluding route segments with the opening of new subway stations in the period)

	I	II	III
Morning	0.162***	0.116***	0.0915
	(0.0487)	(0.0399)	(0.0718)
Afternoon	-0.197*	0.156**	0.0709
	(0.113)	(0.0736)	(0.100)
Morning and afternoon	0.0734**	0.0998***	0.0408
	(0.0289)	(0.0323)	(0.0668)
Critic time	-0.0694	-0.0734	-0.0139
	(0.0617)	(0.0639)	(0.0903)
Year and month	Yes	Yes	Yes
District employment	No	Yes	Yes
Speed reduction	No	Yes	Yes
Taxi traffic allowance	No	Yes	Yes
Route segment controls	No	Yes	Yes
# Lanes and veic. part (%)	No	No	Yes
Cluster-robust	Yes	Yes	Yes
Observations	12,924	12,924	4,074
R^2	0.008	0.124	0.194
Cluster	669	669	177

Authors' elaboration.
Obs.: This table presents results using fixed effects to the variable average speed (natural logarithm). We use standard error corrected by route cluster. Standard error is shown in parenthesis. ***, ** and * represent significance level at 10%, 5% and 1%, respectively.

TABLE A.5

Effect of the bus lanes on the average speed of vehicles that do not travel in the bus lanes by city zone (excluding route segments with the opening of new subway stations in the period)

	I	II	III
North	0.0118 (0.0224)	–	–
South	-0.0148 (0.0646)	-0.0454 (0.0699)	0.00344 (0.118)
East	-0.0595 (0.104)	0.0778 (0.0584)	0.0172 (0.0619)
West	0.133*** (0.0252)	0.109*** (0.0403)	0.150*** (0.0511)
Centre	-0.140* (0.0784)	0.0900* (0.0488)	0.0115 (0.0817)
Year and month	Yes	Yes	Yes
District employment	No	Yes	Yes
Speed reduction	No	Yes	Yes
Taxi traffic allowance	No	Yes	Yes
Route segment controls	No	Yes	Yes
# Lanes and veic. part (%)	No	No	Yes
Cluster-robust	Yes	Yes	Yes
Observations	12,924	12,924	4,074
R^2	0.007	0.124	0.194
Cluster	669	669	177

Authors' elaboration.

Obs.: This table presents results using fixed effects to the variable average speed (natural logarithm). We use standard error corrected by route cluster. Standard error is shown in parenthesis. ***, ** and * represent significance level at 10%, 5% and 1%, respectively.

Data da submissão em: 8 set. 2022.

Primeira decisão editorial em: 27 set. 2022.

Última versão recebida em: 28 dez. 2022.

Aprovação final em: 10 jan. 2023.