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Congestion Charge in São Paulo city: Likely Traffic Effects

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ABSTRACT

Aiming to reduce vehicles traffic in the downtown of Sao Paulo (Brazil), a circulation restriction policy known by "rodizio" (or "rotation") was implemented in 1998. Even though this policy is in place for more than a decade, the increase in the traffic gridlock since then is indicating more effective policies are required. Thus, the present report aims to estimate the welfare and traffic effects of a hypothetical congestion charge in São Paulo. In order to do so, this study explores microdata of the Origin-Destination survey carried out by São Paulo's subway company. As for methodology, this research will employ discrete choice methods to identify structural parameters. From these estimates, the likely effects on traffic flows and consumer surplus of imposing different a congestion tax or an extension of the existing rotation system were estimated. The increase in the reach of the existing rotation system implied in a significant shift from car to bus travels, especially in the case of work trips. This result remained robust for all econometric models that were simulated. On the other hand, the simulations on congestion charging lead to a smaller shift from driving to other modes of public transportation modes. Finally, the simulated welfare effects for the increase of the rotation system would have a lower loss of consumer surplus for education trips when compared to congestion charge. For work trips, the results are not conclusive.

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Summary

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1 – Introduction

Aiming to reduce vehicles traffic in the downtown of Sao Paulo (Brazil), a circulation restriction known by "rodizio" (or "rotation") was implemented in 1998. The rule is simple, cars with license plates terminated by 0 and 1 are prohibited to circulate around downtown on Mondays, and cars with license plates terminated by 2 and 3 cannot circulate on Tuesdays, and so on. Even though this policy is in place for more than a decade, the increase in the traffic gridlock along the years is showing that more effective policies are needed.

The present report aims to estimate the welfare and traffic effects of a congestion charge in São Paulo. In order to do so, this study explores microdata of the Origin-Destination survey carried out by São Paulo"s subway company. An empirical methodology, based on discrete choice models, will be used to identify structural parameters of the individual"s demand for transport. These demands will be used to run counterfactual exercises to predict the resulting effects on traffic and welfare of a congestion charge.

The impacts on welfare will be measured by the variations on consumer surplus in response of the increase in the travel's cost. Variations in the welfare caused by pollution or gridlock are not in the scope of the present study.

Since seminal works of Walters (1961) and Vickrey (1969), traffic congestions have been interpreted as negative externalities generated by peak demand in excess of the available supply. There are many definitions of externality, but in congestion context one can define it as "an effect of use decision by one set of parties on others who did not have a choice and whose interests were not taken into account"[1]. In that sense, when a driver decides to use a road during a peak demand he imposes a congestion cost (negative externality) upon other drivers.

Economic theory postulates that this externality can be corrected by charging the equilibrium price. Being more specific, each driver should pay for the additional congestion they create. The goal of this policy is to use price mechanism to make users more aware about the costs they impose upon the society when consuming during peak demand.

[1] Definition by Peter B. Meyer, from www.econterms.com

Traffic gridlock in urban areas generates various problems, such as productivity losses, increased fuel consumption, lowering in the quality of life as well as assorted environmental effects. Such problems are even worse in major urban areas in developing countries, where adequate infrastructure is usually lacking.

The excessive number of automobiles is usually a response to the insufficient supply of adequate public transportation in terms of comfort, timeliness and safety. A natural consequence is the necessity of public policies that aim to reduce the usage of private transportation in certain periods of the day.

One possible alternative is the restriction of car usage during some periods of the day, in certain days of the week. This kind of policy has been used in many urban metropolitan areas in England, Norway, Canada, Singapore, Mexico and Brazil. Specificities of these restrictions may vary from complete prohibition of car usage (subject to fines, if disobeyed) to various forms of congestion taxes, with effective impacts on reducing traffic during rush hours.

In the next sections the partial results of the research will be discussed. First, the descriptive statistics of the Origin-Destination Survey are presented. In the sequence, we start by reviewing the existing set of traffic restrictions, following by a review of existing congestion charge policies, with a detailed policy proposition. Finally, we discuss the econometric methodology to be followed to estimate the effects of these measures.

2 – Background: The existing Traffic Restrictions

The most important existing arrangement designed to reduce the automobile traffic is the so-called Rotation System (in Portuguese, Rodízio), imposed by the Municipality of São Paulo in 1997 (Decree 12.490 of Oct. 3, 1997). At the time, the city government said the main reason for the Rotation was the worsening of the air quality in the city. However, a side effect (it is not clear whether it was an unintended side effect, though), was the reduction in traffic gridlock right after the start of this system.

From then on, the circulation of private vehicles, excepting those of essential functions, public transportation and school busing, ambulances, disabled persons was prohibited in a specific area corresponding to the expanded city center, according to the last digit of the license plate, as in the table below:

Table 1 - License Plates not allowed to Circulate

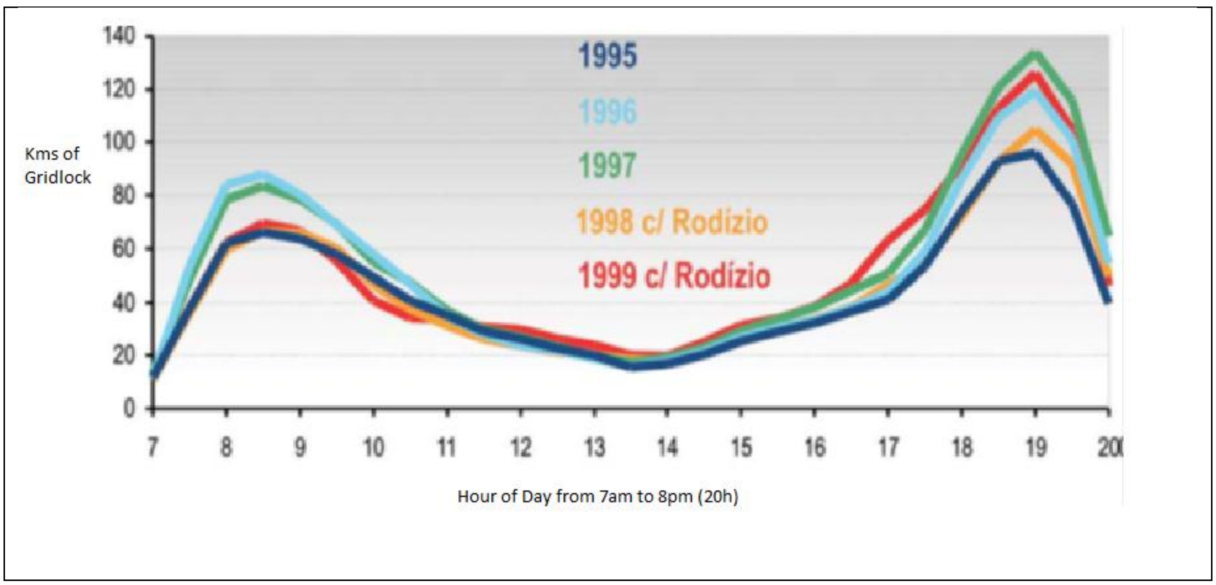
Weekday	Last Digits Prohibited
Monday	1 and 2
Tuesday	3 and 4
Wednesday	5 and 6
Thursday	7 and 8
Friday	9 and 0

Source: São Paulo Traffic Company (2012)

The prohibition covered to periods each working day: from 7AM to 10AM and from 5PM to 8PM. Those drivers caught driving in the prohibited area are subject to fines and points in the driving record (which could lead either to mandatory driving classes or loss of driver"s license).

The effects of the Rotation System on traffic were more pronounced in its first year, 1998. In 1999 the length of roads considered to be congested (that is, with traffic with a lower speed than usual) already surpassed the pre-Rotation level, as the next figure (from Ferraz and Szasz, 2005) shows:

Figure 1 - Average Gridlock Length during the day (from 7am to 20pm)



Source: Ferraz and Szasz (2005)

Even though the Rotation System did not stop the growth of traffic gridlock, this system was essentially unchanged from 1998 to the present day. In the last mayoral elections, the issue of increased traffic congestion was brought to the attention of all candidates. Unanimously, they rejected both the proposal of a congestion tax and an extension of the Rotation System (presumably by increasing the number of last license plate digits to be prohibited to circulate in a given weekday); they instead focused on investing in public works and on expansion and improvement of the existing public transportation systems (especially busing). However, given the low public appeal of both proposals – congestion tax and increased Rotation System – it is quite unlikely a candidate with some chance of winning put this sort of proposal in his program.

Another potential difficulty with the congestion tax in such a large city as São Paulo is the practical implementation of the measure. In this case, the evolution of technology is encouraging. From 2014, it is expected new cars to be equipped with electronic tags enabling them to be monitored and, if it turns to be the case, billed according the location of the automobile.

Whatever the alternative to be chosen in the future (or even neither an increased Rotation System nor a Congestion Charge), the effectiveness of any measure depends on knowing the traffic structure of the city and the existing arrangements. The next section is focused on presenting some transportation statistics of the São Paulo Metropolitan Area.

3 - Transportation Statistics

The main source of transportation statistics of this study will be the Origin-Destination survey carried out by the São Paulo Subway Company. This survey has 169,625 observations, with information about trips made in 2007 in the region composed by 38 municipalities besides São Paulo city Figure 2, area known as Metropolitan region of São Paulo marked in yellow (38 municipalities) and in orange (São Paulo city).

Figure 2 – São Paulo Metro Area

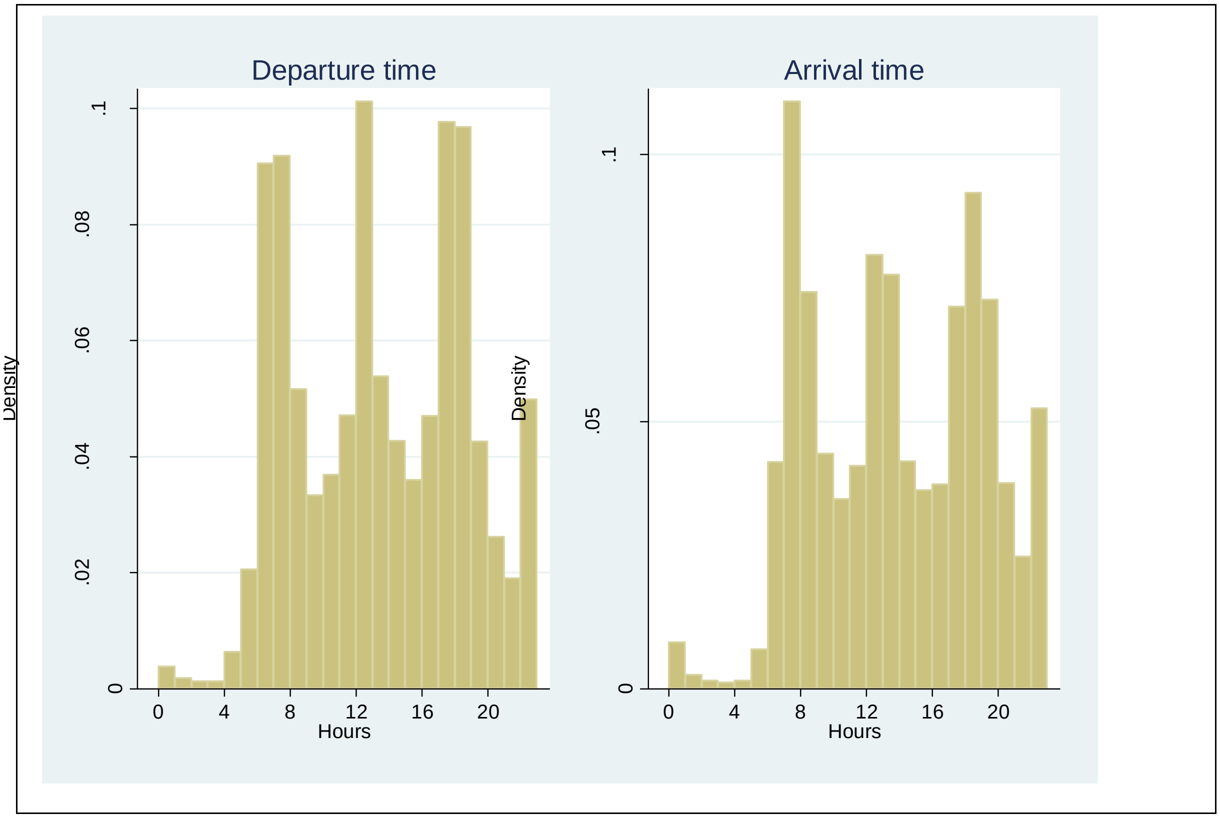
Source: Origin and Destination Survey, São Paulo (2007)

The survey has a wide range of information about the individuals, such as income, car and home ownership, household size and other characteristics which could influence the decision of whether or not take the trip and what transportation mode to use. The survey also has trip information as departure and arrival time, mode transportation, reason of the trip – leisure or work – and so on.

Some preliminary analyses were made regarding the trip features, the characteristics of the individuals and their relationship, and the results are presented below.

3.1 - Trip distribution during the day

Figure 3 - Distribution of Departure and Arrival time



Source: Origin and Destination Survey, São Paulo (2007)

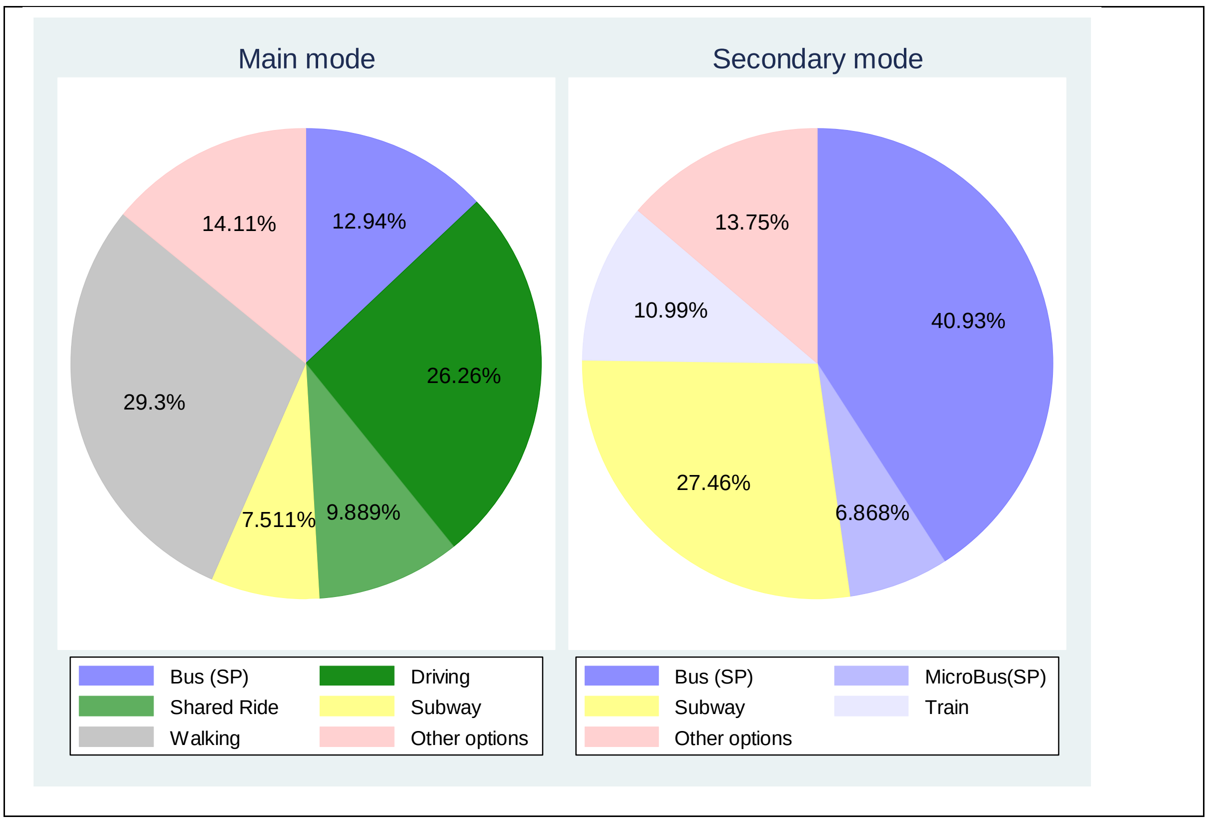
The trips are concentrated mainly during three periods of the day, between 6 and 9 AM, between 12AM and 1PM and between 5PM and 7PM.

3.2 - Usage of Transportation Mode

One important feature of the trips is that some individuals may use more than one transportation mode. Among the 169,625 trips related in the survey, 21,304 (12.6%) are made with more than one transportation mode: 17,313 (10.2%) individuals use two, 3,627 (2.1%) use three and 364 (0.2%) use four modes.

The share of each transportation mode used as principal and secondary modes are shown in the Figure 4.

Figure 4 - Share of transportation mode (main and secondary mode).



Source: Origin and Destination Survey, São Paulo (2007)

The figure above shows that Car is the most used transportation mode, with driving and shared ride summing 36.15% of the trips. Walking is also a very important main mode, with 29.30%. This happens because an important part of the sample is constituted by short trips – trips shorter than 2 Kilometer, sum 44.22% of the sample.

In order to identify the most important pairs of transportation modes, the table below shows the most important options used as primary mode and the frequency that these modes are used with another mode.

Table 2- Frequency of trips by mode and frequency that these modes are used with a secondary mode

Mode	Main Mode	Main mode with secondary mode
Municipal bus	21,946	5,961
Driving	44,538	1
Shared Ride	16,775	11
Subway	12,740	8,475
Walking	49,699	0
Other Options	23,927	2,865

Source: Origin and Destination Survey, São Paulo (2007)

The table shows from the 21,946 times municipal bus was used; in 5,961 (27.2%) it was used with a secondary mode. This relation is bigger for the subway, transportation mode used with a secondary mode 8,475 times (66.5%) from the 12,740 times that it was used as a main mode. Therefore, the modes that are used more frequently with a secondary mode are the municipal bus and the subway, which means that a huge part of the sample uses public transportation when more than one transportation mode is used.

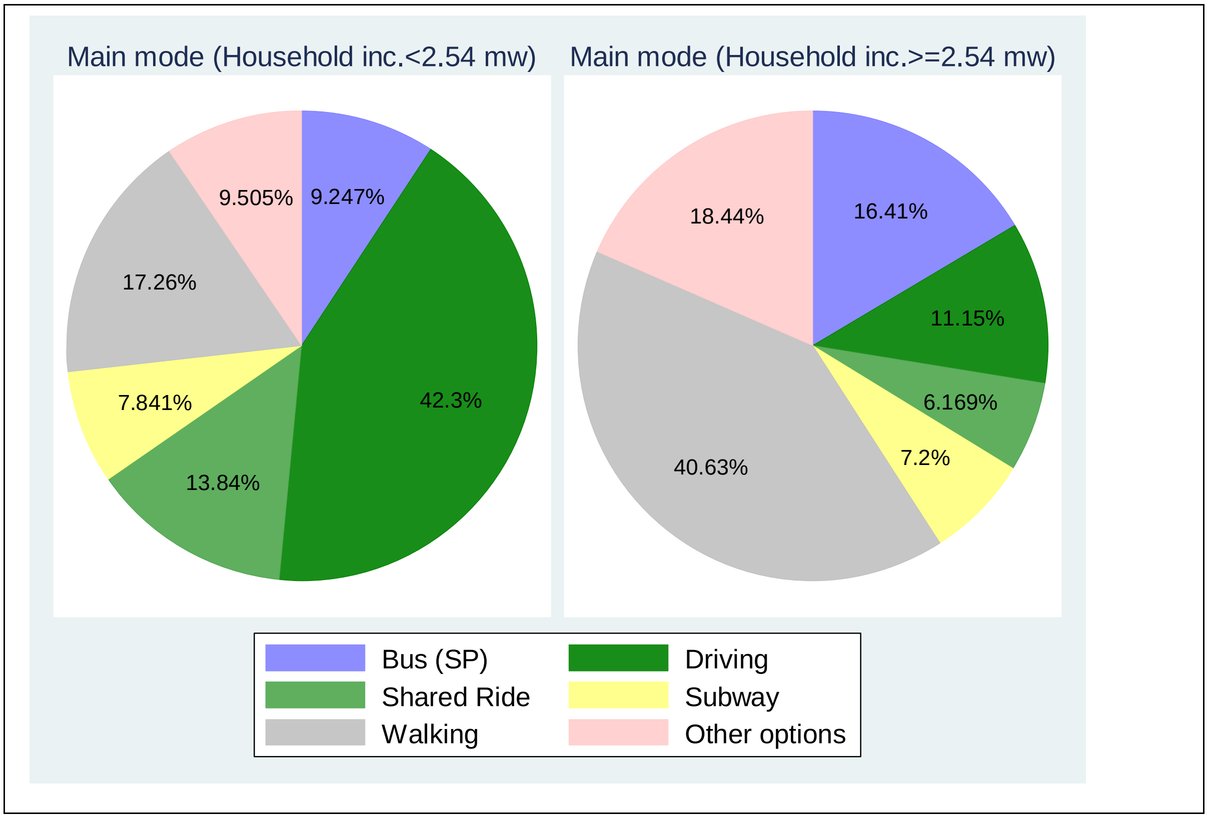
At this point it is important to explain a relevant characteristic of the survey. When the individual has to walk or ride a bicycle in order to get another transportation mode, the survey considers this trip as made only by the second transportation mode (e.g. if the individual walk to the bus station, the survey consider it a trip made by bus no matter the distance that the individual has walked). Therefore, "more than one transportation mode" indicates trips made by more than one transportation mode not considering walking or bicycle.

Considering the 17,313 trips made with two transportation mode, the most common combination are more than one municipal bus, more than one line of the subway, and their combination – municipal bus and subway – with 11,621 individuals using these combinations of modes. This information is important to categorize the different transportation modes in the groups of options to be considered.

3.3 - How individual characteristics are related to the transportation mode choice?

It is expected that individuals of families with higher income are less inclined to use public transportation. The Figure below shows the percentage of transportation mode used by households with income above and below the sample mean (2.54 minimum wages - mw).

Figure 5- Main transportation mode for families with minimum wage above and below the sample mean



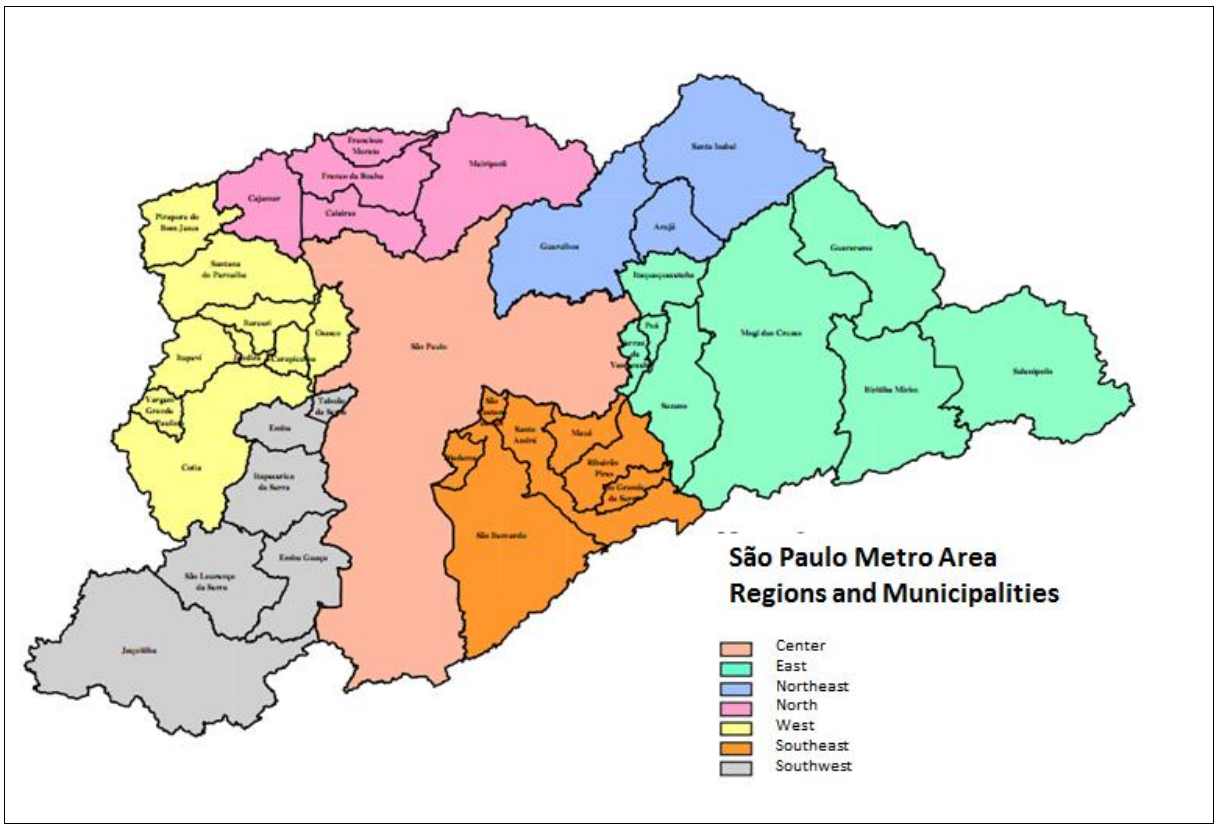
Source: Origin and Destination Survey, São Paulo (2007)

The share of car trips (driving and shared ride) in the group with higher income is 56.14% and in the group with smaller income is 17.32%. The opposite occurs if we consider the walking option, which share is 17.26% in the richer group and grows to 40.53% in the poorer. A similar pattern is observed in the municipal bus alternative, which increases from 9.25% to 16.41% from the richer to the poorer group. The share of subway usage is similar in both groups.

3.4 - Which zones have more intense traffic?

As mentioned above, the survey contains information about trips made in 39 municipalities that compound the metropolitan region of São Paulo. These municipalities are aggregated in seven zones: São Paulo city (center), East, Northeast, North, West, Southeast and Southwest (Figure 6).

Figure 6 - Regions of São Paulo Metro Area

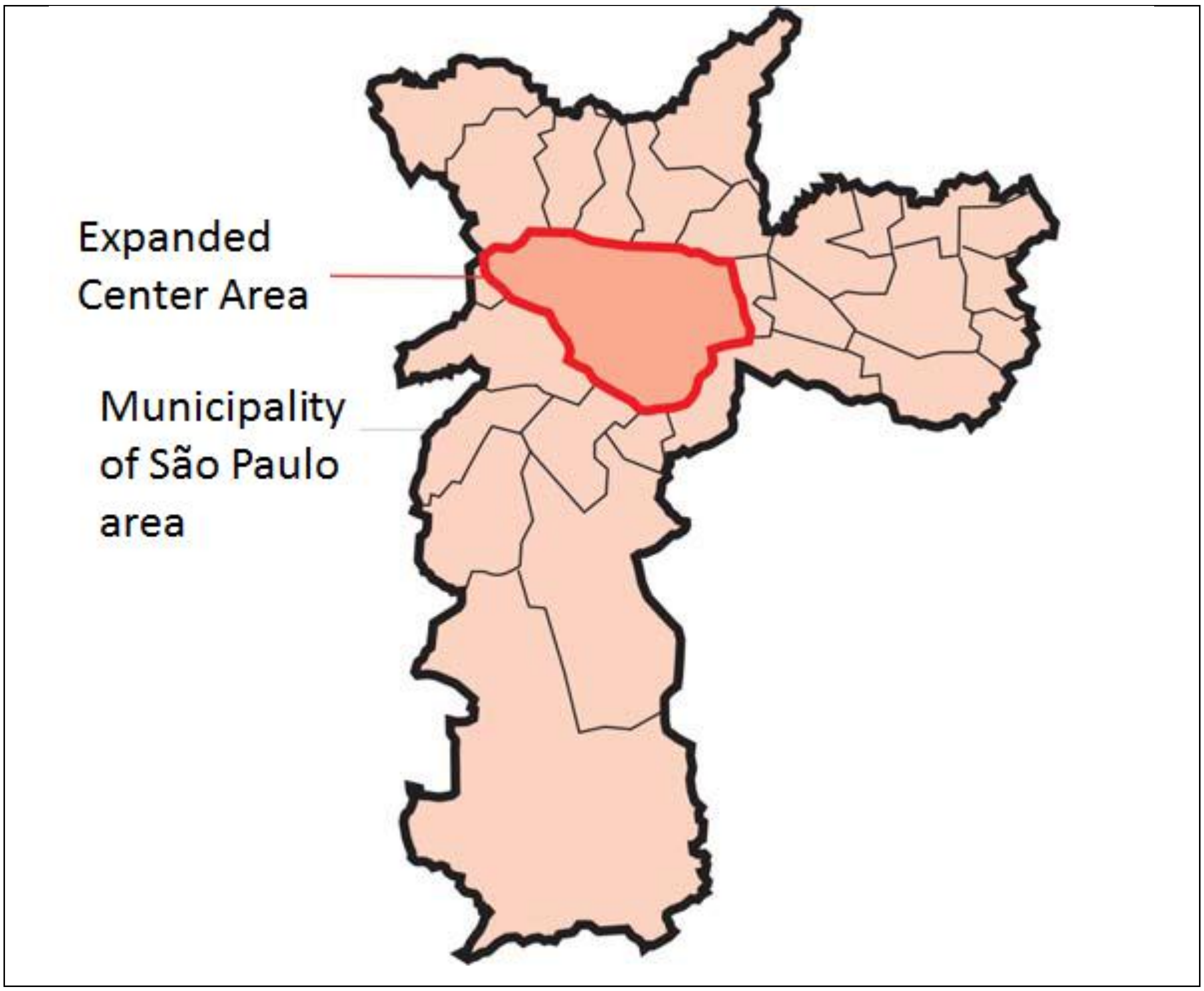


Source: Origin and Destination Survey, São Paulo (2007)

Another important division of the zones is the Expanded Center of São Paulo City. Since it is the part of the city where the restriction to traffic is applied, it is important to study specifically this area.

The Expanded Center of São Paulo city is composed by 17 of the total of 460 zones that compound the sample and it is located right in the center of São Paulo city. This region has a very intense economic activity and therefore it is expected that it has the most intense traffic. The Figure below from Ferraz and Szasz (2005), highlights this region in the São Paulo city:

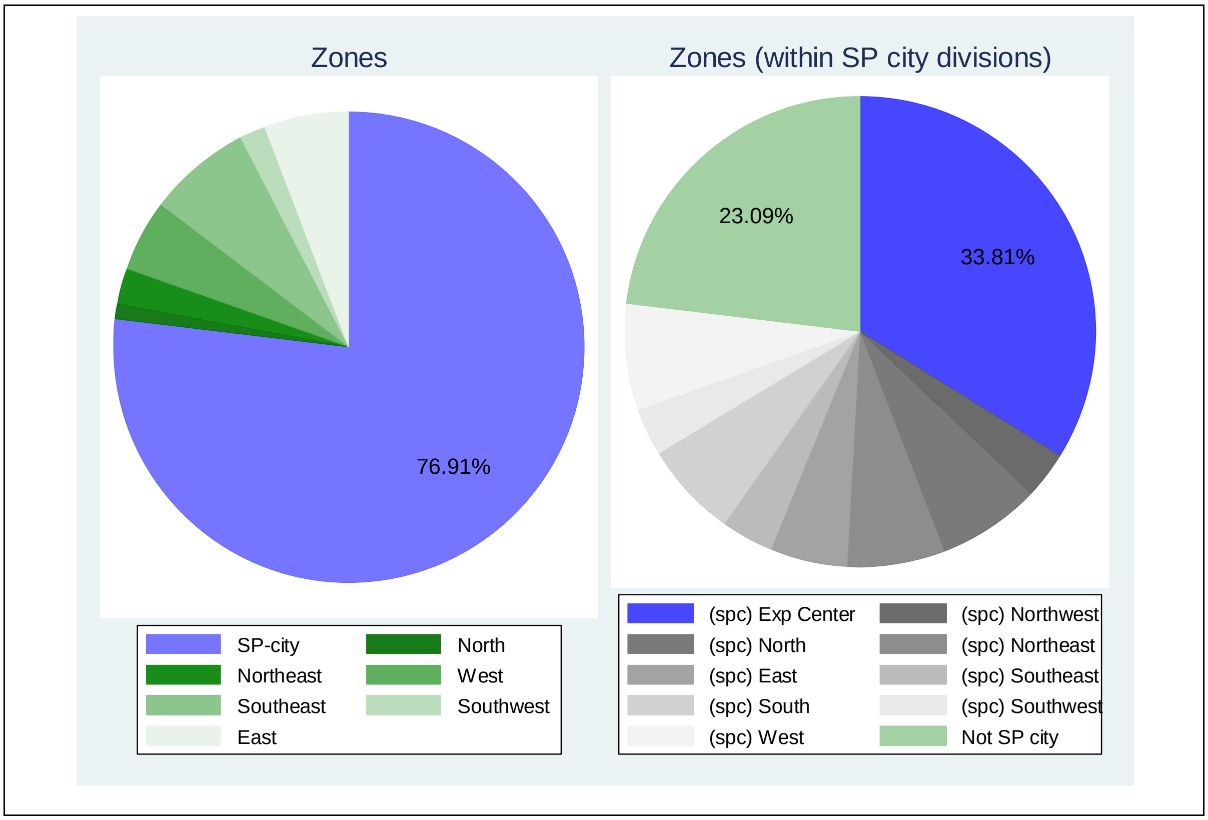
Figure 7 - Expanded City Center



Source: Ferraz and Szasz (2005)

Figure shows the share of each area in the total of trips, considering origin and destination. The figure on the left divides the zones in 7 regions: São Paulo city (center), East, Northeast, North, West, Southeast and Southwest. The figure on the right shows the same data, but considering also the divisions inside São Paulo city (all in gray, except the expended center) in order to highlight the importance of the trips related to the expanded center.

Figure 8 - Travel Shares in São Paulo Metro Area and São Paulo City



Spc = São Paulo City

Source: Origin and Destination Survey, São Paulo (2007)

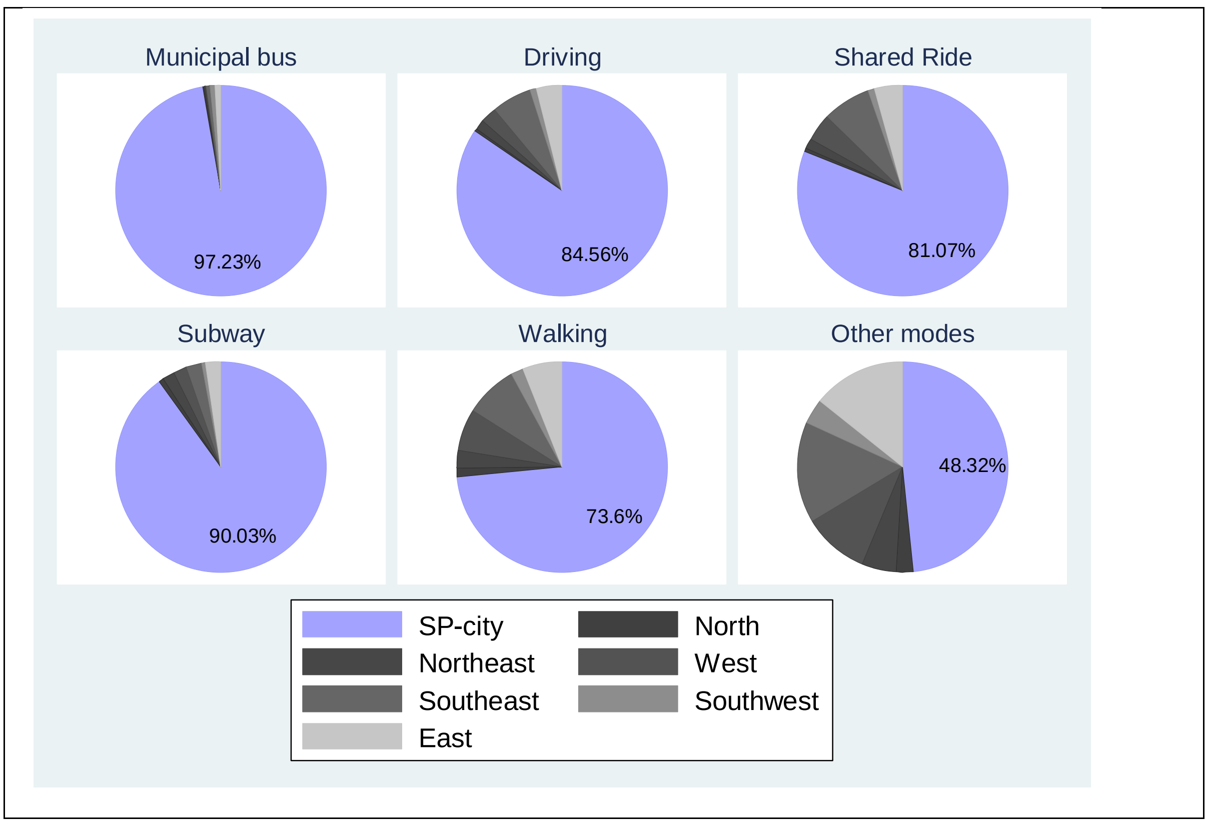
The first panel of Figure 8 shows that the area which has the highest number of trips is São Paulo city, the destination or origin of 76.91% of all trips. The other areas sum 23.09% of the trips. This illustrates the importance of São Paulo to the cities located nearby, since 38 municipalities together have a much lower frequency of trips than São Paulo city.

Regarding the regions inside São Paulo city, the expanded center is the most important region, with 33.81% of total trips of the survey. It means that more trips were made in this region than in all the other municipalities together except São Paulo. Thus, São Paulo has a great frequency of trips and these trips are very concentrated in the expanded center, which may be reflected in the traffic problems in this area.

3.5 - Which zones are more important by each transportation mode?

Considering that São Paulo city is the most intense traffic region, it is expected that this region is the destination or origin of a large part of the sample for all transportation modes, what is shown in the Figure below.

Figure 9 - Zones of destination/origin by main transportation mode (2007)

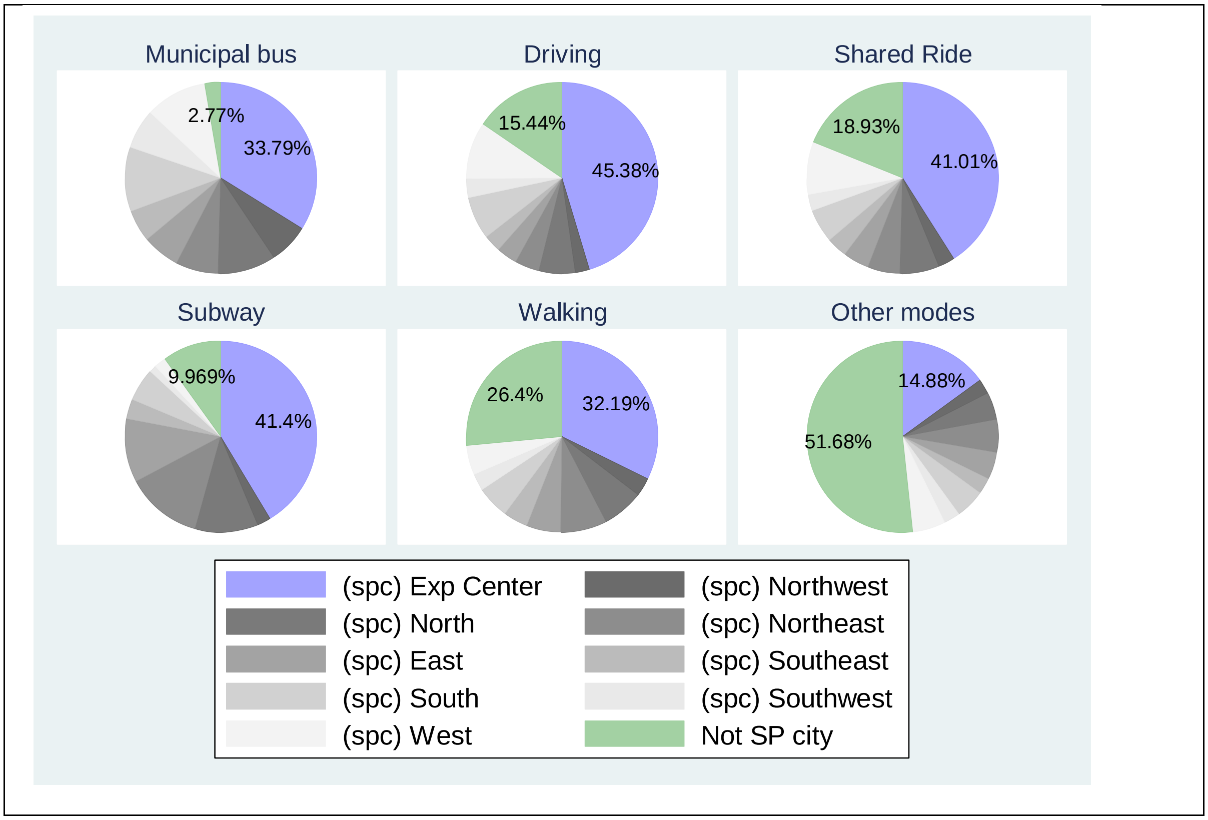


Source: Origin and Destination Survey, São Paulo (2007)

More than 80% of the individuals whose main transportation mode is municipal bus, car (driving and shared ride) and subway goes to or come from São Paulo City. In the case of subway this was expected, since this transport covers this city only. Walking and other modes of transportation trips are made from/to other regions than São Paulo city more frequently.

Figure 10 shows the same data but considering different regions inside São Paulo city.

Figure 10 - Zones of destination/origin (considering different regions of São Paulo city) by main transportation mode



Spc = São Paulo City

Source: Origin and Destination Survey, São Paulo (2007)

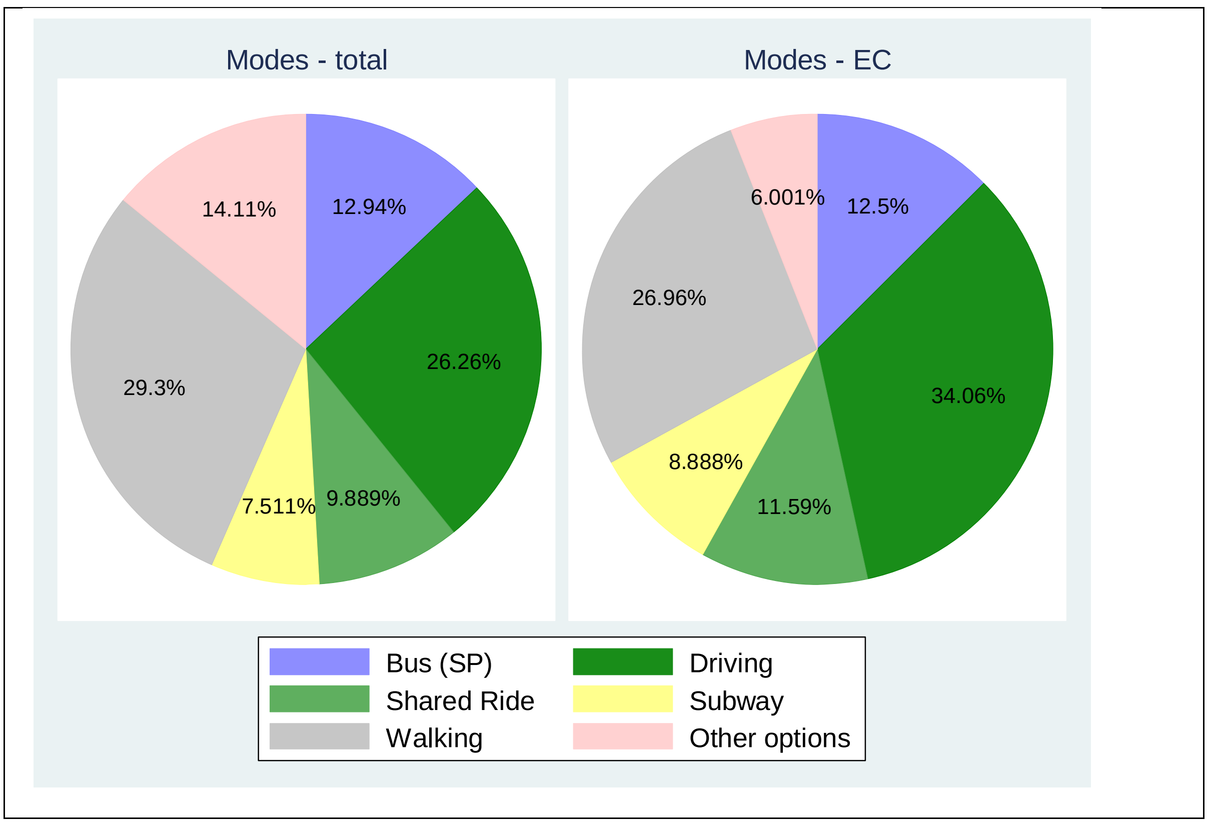
Driving is the more frequent transportation mode used when the expanded center is either the trip origin or trip destination. Almost half of the individuals that use car go or come from the expanded center, which may be one of the reasons that make the traffic in the region so intense. Regarding the public transportation modes, subway is more frequently used to go to the expanded center than bus.

3.6 - Expanded Center trips

Since the Expanded Center (EC) is related to a very important part of the trips in the survey and it is the zone in which the current traffic restrictions are imposed, it is important to analyze some features of this region.

Regarding the transportation mode, driving is the most important transportation mode for trips to or from the expanded city center. Figure 11 shows the share of trips by each main transportation mode for the entire sample and only for the travels related to the expanded center.

Figure 11 - Modes of transportation for all sample and for trips related to expanded center (2007)



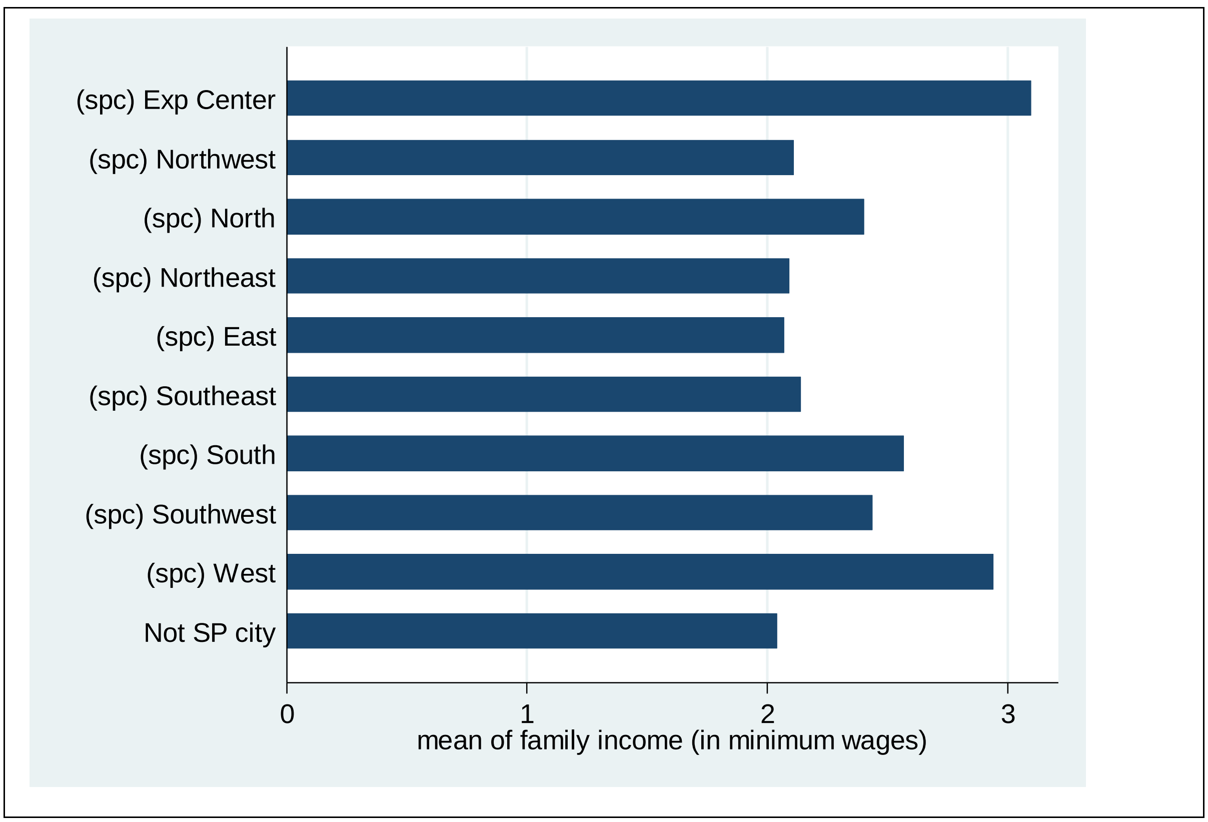
Source: Origin and Destination Survey, São Paulo (2007)

Driving and shared riding sum 36.1% in the sample, but considering only the trips related to the expanded center this sum increases to 45.6%. The other modes have similar shares in both groups.

This part of the descriptive analyses implies that, even with the actual restriction to usage of private vehicles, driving and shared rides are the most important options in trips related to the expanded center, which shows the importance of alternatives restrictions of individual transportation modes usage in the Expanded Center of São Paulo.

Since probably there is a relationship between car ownership and familiar income, it is also expected that trips related to the expanded center are made by individuals with higher familiar income, what is shown in Figure 12.

Figure 12 - Mean Family Income across Origin/Destination Regions in São Paulo City



Source: Origin and Destination Survey, São Paulo (2007)

To sum up, the characteristics above point out to the Expanded City Center being an important trip origination and trip destination region, especially for automobiles, despite being subject to the traffic restrictions discussed in section 2 of this report. These points indicate the *Expanded* center to be the natural choice for further restriction measures. Since the Rotation System is already in place and its essential features are not expected to change in any likely increase in its breadth, we chose to review the international experiences with Congestion Charges, in the next section.

4 – International Experiences on Congestion Charging

4.1 - Singapore

Singapore was the first city in the world to adopt congestion pricing. The Electronic Road Pricing (ERP) was implemented in 1998 to reduce traffic at roads into Singapore's central business district.

The ERP is an electronic system of congestion pricing based on a pay-as-you-use principle. The scheme consists of gantries located at roads with heavy traffic (nowadays, there are around 80 gantries in Singapore). When a vehicle goes through a gantry it is automatically charged. The value of the charge depends on the location and time - the same route can cost up to 8 times more during the peak hours. Moreover, charges may change on quarterly basis, depending on traffic conditions - in that sense, the pricing scheme is endogenous.

Every vehicle that wishes to use the priced road must be equipped by a device known as "In-vehicle Unit" or simply "IU". These devices carry a stored-value card that is automatically charged when the vehicle crosses a gantry. An IU costs SGD150 (around USD120) being mandatory for all registered vehicles that use priced roads.

If a vehicle goes through the ERP without sufficient value stored in the IU, the owner must pay the regular charge plus an administration fee of SGD10 (around USD8). In the case of no payment within 30 days, the fine can reach SGD1000 or 1 month in jail.

According to the Land Transport Authority (LTA) - the official Singapore's transport agency - "ERP has been effective in maintaining an optimal speed range of 45 to 65 KM/H for expressways and 20 to 30 km/h for arterial roads". Additionally, they reported that traffic has gone down by 13% within the ERP zone. On the other hand, users complain that the implementation of an ERP gantry along any road simply moves the traffic somewhere else, causing more traffic along smaller roads.

4.2 - London

Inspired by the Singapore experience, the London congestion charge was introduced in 2003 with the goal of reducing congestion and rising funds to be reinvested in the London transport system. The standard fee is £10 daily if a driver goes into the Congestion Charge Zone (CCZ) between 7AM and 6PM, Monday to Friday. Transport for London (TfL) is responsible for the charge which has been operated by IBM since 2009.

There tariff scheme constitutes a mechanism that aims to encourage early payments. The fee remains £10 if paid by midnight on the day of travel, but it rises to £12 if paid by the end of the next day. Failure to pay implies an extra fine of £120, which can be reduced to £60 if paid within 14 days or increased to £187 if unpaid after 28 days.

There are many ways to pay the Congestion Charge: internet, text message, phone, post or Auto Pay. In this last case, drivers pay less (£9) and avoid fines.

Residents living within the CCZ receive a 90% discount. Moreover, electrically propelled vehicles, greener vehicles, motor tricycles or vehicles with nine or more seats get 100% discount.

Enforcement is primarily based on Automatic Number Plate Recognition (ANPR). There are cameras at entrances, exits and around the CCZ. These cameras read the plates' number and check them against a database to work out whether the charge was already paid, are exempt, or have a 100% discount. If any payment is made until midnight of the following charging day the registered keeper of the vehicle receives a penalty charge notice.

In 2007, TfL elaborated a report showing that the number of chargeable vehicles entering the zone had reduced by 30% (primarily cars and miniTaxis) compared to 2001, while there were increases in the numbers of taxis, buses, and especially bicycles. According to the same report, the daily profile of traffic flows had changed as were expected - less traffic after 9:30AM and a peak immediately before and after the end of the charging period. The overall level of traffic of all vehicle types entering the central CCZ has being consistently lower since the charging system was implemented. Probably these long term trend of less traffic entering the charging zone is reflecting changes in the people's lifestyle.

In the first years after congestion pricing being implemented, the time of car trips within the charging zone decreased significantly. On average, journeys become 0.7 minutes faster (per km), representing a decline of 30% on the average journey's time compared to 2001. But over the years this impact has becoming smaller. TfL argument that journeys would become even slower if the scheme was not put in place.

According to the Annual Report and Statement of Accounts 2006/07, the revenues from the congestion charge were £252.4 million, which represents 8.5% of TfL's annual revenues. More than half of this amount (£130.1 million) was spent on the cost of running the toll system. After paying all the operating costs, the net income was £89.1 million for TfL.

4.3 - Stockholm

The Stockholm Congestion Tax (SCT) was implemented on a permanent basis in 2007, after a seven-month trial period and a referendum that approved the system. The SCT is a congestion pricing system that charges Swedish-registered vehicles that are driven into and out of central Stockholm, Mondays to Fridays, between 6:30AM and 6:30PM. As occurs in other cities, the primary purpose of the congestion charge is to reduce traffic congestion and improve the environmental situation in Stockholm.

During the trial period taxes were between US $1.50 and 2.75, depending on time of day. Traffic was reduced 22% and mobility improved significantly. Public transport use increased by around 4.5%. Moreover, carbon dioxide emissions were reduced around 14% in the inner city, compared to pre-toll levels.

Although the SCT was inspired by the London‟s congestion charge, they keep important differences. In London, the goal was keep car out of the city center. In order to achieve this goal, London installed hundreds of cameras throughout the congestion zone, charging £10 to anyone driving within it. Stockholm‟s goals were different. Rather than keeping cars out, the Stockholm was more interested in evenly distributing the flow of traffic entering its city center. In that sense, Stockholm introduced a variable pricing system.

While London charges one fee for the entire day, Stockholm‟s daily charges add up every time you enter or leave the charging zone. The mechanism of payment also differs. London‟s drivers have until the following day to pay their charge, but Stockholm bills its road users at the end of the month. In both cities the so-called „green vehicles‟ are exempt from the fee, as are motorcycles and taxis.

Vehicles are automatically registered when goes through the 'control points' during the periods when congestion tax is charged. Each passage costs SEK 10, 15 or 20, depending on the time of day. The maximum amount per day and vehicle is SEK 60. The control points merely register when the vehicle passes and a bill is sent to the vehicle owner at the end of each month. Failure to pay the bill results in a reminder bill being sent with an added 500 SEK fine. If the reminder fee is still unpaid after 30 days, the case is sent to the Swedish Enforcement Administration, which adds an additional fee of at least 600 SEK.

According to the Swedish Road Administration public transport has seen a 4.5% increase in ridership, traffic is down by 18%, and waiting time to enter the city center during peak hours has been reduced by 50%. Also, there have been environmental and economic benefits: carbon emissions have dropped by 14-18%, ownership of tax-exempt environmentally sustainable vehicles has almost tripled, and retailers have seen a 6% increase in business.

4.4 - Comparing Singapore, London and Stockholm Experiences

In 2008, a report entitled "Lessons Learned from International Experience in Congestion Pricing" demanded by the U.S. Department of Transport compared the congestion pricing experiences in Singapore, London and Stockholm. Below we resume the main findings and conclusions of the mentioned report on mobility, revenue/costs, economy and business, environment and acceptability.

Mobility: All of the three cities have reached their main objective of reducing congestion and keep it at lower levels. In Singapore, London and Stockholm traffic in the priced zone reduced around 10% to 30%, and that reductions were sustained over time. As consequence, the speeds increased significantly within the priced zone. In the three cities, up to 50% of those car travels through the priced zone have shifted to public transportation.

Revenues/Costs: All of the three cities are generating revenues far in excess of costs. In Singapore, revenues have been over 10 times the operating costs. In Stockholm and London the revenues have been over twice the costs. In these two cities, revenues are used mainly to recover operating and enforcement costs, although the original idea was to use revenues to improve public transportation. In Singapore, the great surplus of funds has allowed the government to implement new public transportation programs.

Economy and Business*:* In general, the impacts on economy and business aspects have been neutral to positive. In Singapore, the ERP did not change significantly business conditions and the community responded positively to the program. In London, CCZ has neutral regional economic impacts and the business communities continue to support the scheme. Finally, in Stockholm, until 2008 no significant impacts were identifiable.

Environment*:* The three cities have experienced a better environment as consequence of the smaller number of trips (and carbon dioxide emissions) inside the charged zone. Besides the reduction in the number of trips, the increasing number of "green cars" as a result of the smaller fees has becoming the air quality even better.

Acceptability*:* Public acceptance depends on all aspects listed above, and in that sense is very difficult to measure. Congestion pricing is highly controversial with the public, both before and after implementation. Stockholm minimized that controversy through a referendum. In general, the main fear of the populations is that congestion pricing program will become just another tax.

4.5 - Other International Experiences

A great number of cities around the world have experienced some kind of congestion pricing. Here we will shortly resume some of these experiences.

In Toronto, Canada, the Highway 407 is equipped by an electronic system that reads the licenses plates and then send bills to the car's owner. In Dubai, United Arab Emirates, a similar congestion pricing scheme was implemented in 2007.

Since January 2008, Milan has been experienced a pricing scheme named Ecopass with the objective of reduce carbon emissions and incentive the use of alternative fuel vehicles.

Other Europe small cities, such as Durham, England; Znojmo, Czech Republic; Riga, Latvia; and Valletta, Malta, have implemented congestion charges aiming to reduce traffic and pollution, especially during the peak tourism season.

Finally, other cities have their proposals rejected, such as: Hong Kong (China), Edinburgh (United Kingdom) and New York City (United States).

The results of this section indicate that, despite being controversial and likely to face some serious political hurdles in order to be accepted, a Congestion Charge seems to be quite effective both in terms of costs and in terms of decreased traffic and CO2 emissions. Given these characteristics, we next develop an econometric strategy to estimate some structural parameters needed to investigate the traffic effects of the following policies on top of the existing rotation system:

- A Congestion Charge to be levied in every car trip to or from any region in the expanded center
- A Congestion Charge to be levied in every car trip to or from any region to a subset of all areas of the expanded center
- An extension of the existing rotation system to include more last license plate digits

Further points to be investigated are the equivalent congestion charge: that is, the congestion charge that generates the same amount of traffic reduction of the expansion of the rotation system. Furthermore, we will also investigate some externality effects arising from each measure. The next section will discuss the empirical approach to be used.

5- Inferential Analysis

5.1 – Econometric procedure

The relationship between urban mobility, public policies and transport mode choice makes relevant the analysis of the mode choice of individuals. The empirical analysis of mode choice has a large literature, considering the various alternatives faced by consumers. For instance, some studies consider only the car, motorcycle and public transports as modes (Koppelman and Wen 1998; Bhat 1998, KPMG Peat Markwick et all, 1993), as well as studies which consider also walking and bicycles as alternatives (Lawton 1989; Purvis 1997). Other studies focus on trip motives, some focusing on holiday trips (Iglessias 1997; Marshall and Ballard, 1998), although the most part of the literature is focused on work-related trips.

In such studies, the choice analysis has three basic parts: the decision maker, the alternatives available and a decision rule. For the available database, the intended decision maker whose behavior is to be modeled is an individual, choosing a transport mode for the intended destination.

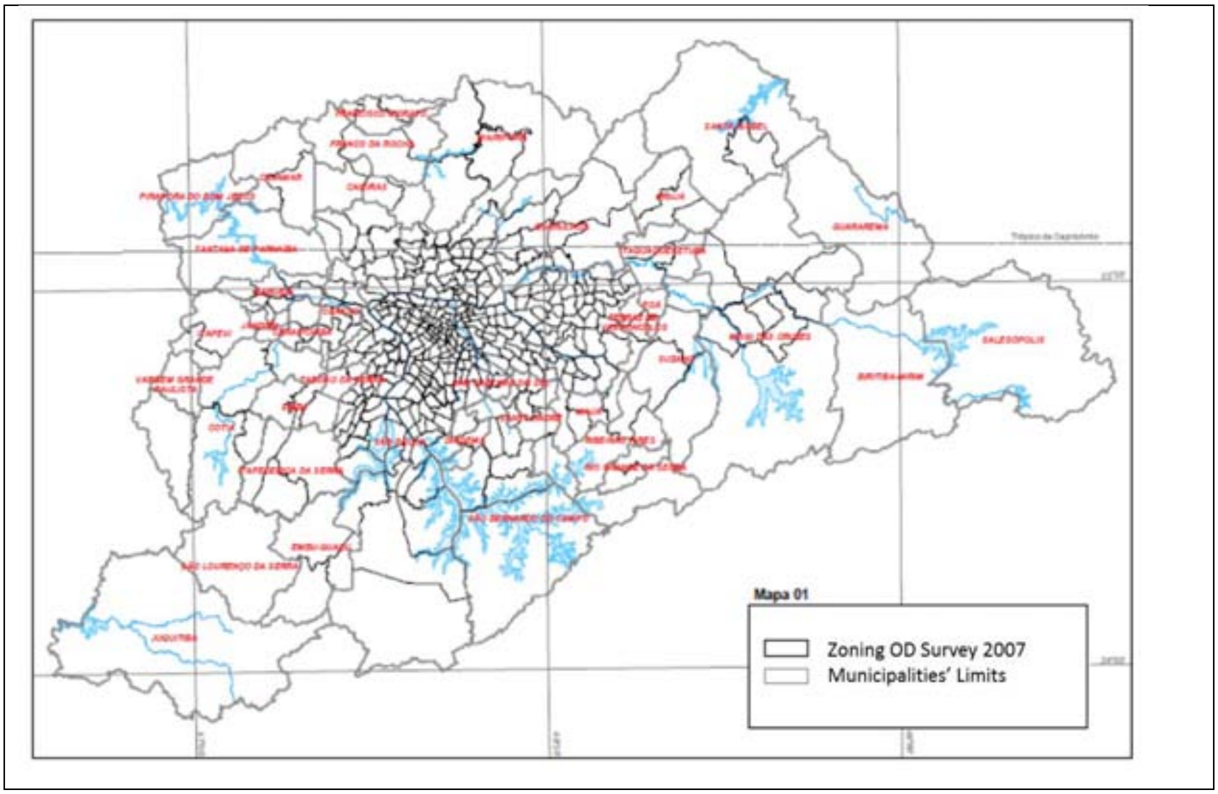
For the available alternatives, database allows the classification of the transportation modes in nine categories: bus, subway, train, driving, shared ride, taxi, motorcycle, bike/walking and combination of more than one public mode (e.g.: subway and buses trips). This classification has left only 0.74% of the trips in the other options group which will not be analyzed.

Finally, the decision rule is an important part of the econometric model, in which it is assumed that the individuals decide rationally, which implies consistent and transitive choices. Even though there are exceptions (Ben-Akiva and Leman, 1985), some important conclusions were drawn using this assumption.

Regarding the econometric technique for the estimation of structural parameters, the natural choice would be the Multinomial and Nested Logit models, with different specifications concerning mode and individual characteristics, as in Koppelman and Bhat 2006. The Mixed Logit may also present interesting results and therefore will also be applied.

In terms of geographic specification, we intend to use the geographic division of São Paulo Metro area in 460 zones, according to the following figure.

Figure 13 - Origin-Destination Zones of the São Paulo Metro Area – 2007 Version of the Origin-Destination Survey



Source: Origin and Destination Survey, São Paulo (2007)

The econometric methods to be used here are quite different from the standard microeconomic framework of selecting a bundle of goods subject to a budget constraint. The differences between the approach pursued here and the traditional microeconomic framework will be discussed in the subsection below.

5.1.1. Discrete Choice Theory

Sometimes consumers have to decide "how much" to demand from certain goods. In such situations, goods are assumed to be continuous variable, and neoclassical consumption models are used to derive consumer's demand. However, sometimes consumers have to decide "which" good to demand. For instance, people have to decide which mode of transport to take to work. In such cases, discrete choice models estimates better the consumer's demand.

In both models consumers are rational, full informed, and seek to maximize their utilities. However, discrete choice models focus on situations in which the potential outcomes are discrete; therefore the optimum choice is not characterized by standard first-order conditions. In discrete choice models the utility depends on the relation between individual's and alternative's attributes (z_{ni}). On the other hand, in neoclassical models the utility depends only on the quantity of goods. Finally, in discrete choice models the utility depends on a stochastic component (ε_{ni}) that doesn't exist in neoclassical models.

In this section we present 2 theoretical models of discrete choice: *multinomial* and *nested logit*. These models constitute the theoretical background of the empirical analysis made in section 5.6.

Consider a population of N individuals. These individuals are potentially heterogeneous, so let s_n be the vector of characteristics of the individual n (e.g. annual income, age, gender). Each individual have to decide which mode of transport to take to work. Suppose they must choose a single alternative from the discrete choice set $I = \{\text{car, bus, train, other}\}$.

We can express the probability that individual n chooses the alternative $i \in I$ as:

$$P_{ni} \equiv \text{Prob(ndividual } n \text{ chooses alternative } i) = G(x_{ni}, x_{ni'}, s_n, \beta) \qquad (1)$$

where

G is a probability distribution function (later we will see that different $G's$ imply different models),

x_{ni} is a vector of attributes of the alternative i faced by individual n (e.g., travel time and cost),

$x_{ni'}$ is a vector of attributes of the other alternatives ($\forall i' \neq i$) faced by individual n, and β is a set of parameters that relate variables to probabilities (which will be estimated in section 5.6).

A few comments before we move on. First, the attributes of the alternatives is allowed to differ over people. In practice, the cost and time for travel to work by car, bus, and rail can be different for each individual depending on the location of home and work of each one. Second, the individual characteristics s_n can be used to calculate choice probabilities. Together, these features will be very useful in our empirical analysis. With them we will be able to forecast how individuals" choices will change in response of changes in the attributes of the modes of transport (such as changes in travel's time and cost caused by the implementation of the congestion charge).

So far, the model only established that choices are random. The natural question is: what determines that random mechanism of choices? A first family of models assumes that individual's decision rule is stochastic, while the utility is deterministic (Luce (1959), Tversky (1972)). On the other hand, a second family of models assumes that the decision rule is deterministic, while the utility is stochastic (McFadden (1978)). This second interpretation is closer to neoclassical choice theory than the first one, what makes it more attractive for our purposes in section 5.6 (once it provides the theoretical basis for calculation of changes in consumer surplus from changes in the attributes of the alternatives of transport).

Define U_{ni} as the utility that individual n obtains from choosing alternative i. Assuming that individual's behavior is utility-maximizing, choices can be represented by a binary variable defined as:

$$y_{ni} = \begin{cases} 1, & \text{if } U_{ni} > U_{ni'} \;\; \forall i \neq i' \\ 0, & \text{otherwise} \end{cases} \tag{2}$$

As seeing above, individual choices depend on many factors that may affect their utility, such as their own characteristics and/or the attributes of the alternatives. Some of these factors can be observed by the econometrician, but some of them are intrinsically impossible to observe (e.g., risk aversion). Once we have stated that, let's assume the utility can be decomposed into two parts: one part depending on observable variables and other depending on non-observables.

$$U_{ni} = \beta z_{ni} + \varepsilon_{ni} \tag{3}$$

where

z_{ni} is a vector of observed variables relating to alternative i for individual n that depends on attributes of the alternative, x_{ni}, interacted perhaps with attributes of the individual, s_n, such that it can be expressed as $z_{ni} = z(x_{ni}, s_n)$ for some numerical function z,

β is a corresponding vector of coefficients of the observed variables, and

ε_{ni} captures the impact of all unobserved factors that affect the individual‟s choice.

Putting (1), (2) and (3) together, the choice probability can be written as

$$\begin{aligned} P_{ni} \quad & \text{Prob(ndividual } n \text{ chooses alternative } i) \\ & \text{Prob}(y_{ni} \quad\quad) = \text{Prob}(U_{ni} \quad U_{ni'},\ \forall i \neq i') \\ & \text{Prob}(\beta z_{ni} + \varepsilon_{ni} \quad \beta z_{ni'} + \varepsilon_{ni'},\ \forall i \neq i') \\ & \text{Prob}(\varepsilon_{ni'} - \varepsilon_{ni} \quad \beta z_{ni} - \beta z_{ni'},\ \forall i \neq i') \end{aligned} \tag{4}$$

Equation (4) says that the probability that individual n chooses the alternative i can be written as the probability that the random terms, $\varepsilon_{ni'} - \varepsilon_{ni}$, are below the observable term $\beta z_{ni} - \beta z_{ni'},\ \forall i \neq i'$. Different choice models (i.e. different specifications of G) arise from different distributions of ε_{ni} for all i.

When ε_{ni} follows an extreme-value distribution, we say that it belongs to the Generalized Extreme Value (GEV) family of models. According to Alves and Neves (2010), the GEV distribution "arises from the extreme value theorem (Fisher-Tippett, 1928 and Gnedenko, 1943) as the limiting distribution of properly normalized maxima of a sequence of independent and identically distributed (i.i.d.) random variables. Because of this, the GEV distribution is fairly used as an approximation to model the maxima of long (finite) sequences of random variables."

In the next sections we describe the multinomial and nested logit models, in both the stochastic term ε_{ni} follows an extreme-value distribution.

The Multinomial Logit (MNL) model is the most basic member of the family of GEV models. Luce and Suppes (1965) showed that the MNL choice probability for individual n and alternative i is given by

$$P_{ni} = \frac{\exp(\beta z_{ni})}{\sum_{j=1}^{J} \exp(\beta z_{nj})}$$

where J is the total number of alternatives.

The MNL model is the mostly used in discrete choice analysis, however is not always suitable, since it assumes that there is no correlation in unobserved factors over alternatives. This lack of correlation results in a property called Independence of Irrelevant Alternatives (IIA). The IIA property implies that MNL model "cannot account for choice situations where a new alternative more than proportionately reduces the choice probabilities of existing alternatives that are similar, while causing less than proportionate reductions in the choice probabilities of dissimilar alternatives" (Anderson, Palma and Thisse (1992)).

A number of models have been proposed to allow correlation over alternatives and avoid the IIA property. Nested and mixed logit, described in the next sections, are among them.

Nested logit models have a smart solution for the IIA problem: they divide the choice set into nests of alternatives according to the correlation between alternatives (i.e., alternatives sharing a nest are more likely substitutes for each other)[2].

While in the MNL model the error terms are distributed in extreme value, in the nested logit model the error terms follow a *joint* generalized extreme value distribution. In other words, the individual error terms follow a univariate extreme value distribution, but the error terms associated with alternatives sharing a nest are correlated with each other (Hess, 2005).

[2] The MNL model is said the most basic member of this GEV family because it uses a single nest of alternatives.

Despite being smart, the solution to the IIA problem posed by the Nested Logit still relies on a large extent on the nesting structure imposed by the researcher. Even though there are some tests that could be carried out on the adequacy of the proposed nesting structure, the choice of a nesting structure is still determined by the researcher.

On the other hand, the solution to the IIA problem by the mixed logit does not depend on an *a priori* nesting structure. It is assumed, under this model, that the coefficients have some sort of heterogeneity – either related to observed characteristics or to unobserved characteristics.

Borrowing the notation of the previous section, we could represent the utility for the consumer n of choosing the alternative i as follows:

$$U_{ni} = \beta z_{ni} + \sigma v_n z_{ni} + \varepsilon_{ni}$$

In which σ is a vector capturing the heterogeneity in the β parameters, and v_n is an idiosyncratic shock (which would be related to observed variables or unobserved ones). Still assuming a distribution for the ε_{ni} term, we could define the choice probability for the individual n of choosing the alternative i. This could be written as:

$$P_{ni} = \int \frac{\exp(\beta z_{ni} + \sigma v_n z_{ni})}{\sum_{j=1}^{J} \exp(\beta z_{nj} + \sigma v_n z_{nj})} dP(v)$$

The integral above is required because it is integrated over the distribution assumed for the v_n terms. Depending on the assumed distribution, the integral for the choice probability could be computed numerically (by some sort of quadrature method), or by simulation.

The effects of the policies discussed at the end of section 2 could be measured directly, as in the changes of traffic between zones of the São Paulo Metro Area, as well as welfare effects from the logsum measure (Small and Rosen (1981)).

5.2 – Dataset

As for the database to be used, this study takes advantage of the microdata present in the most recent Origin-Destination survey carried out by the São Paulo subway company for 2007. In this survey, detailed information on the origin, destination, mode choice and attributes (both individual and chosen transportation mode) were recorded. The survey was carried out by a team of 370 researchers, visiting 54.700 households, with approximately 30.000 of those considered valid after the vetting process of the raw data. The Survey uses a stratified sampling technique, with error margins below 5%.

Even though there is a large amount of information in this survey, the travel costs are not recorded in the database. The next section details the procedures used to recover the travel costs faces by the survey respondents.

5.3 - Travel Costs

The most relevant data which is not completely available in the Origin-Destination survey is the cost of the trips. The methodology applied to obtain the cost of the trips for each transportation mode is described below (the cases in which there is no cost associated with the trip, as in walking/bike and shared ride, are not discussed).

Car

To estimate the cost of car trips the formula below was used:

Cost of trip = [(distance/hour) / (distance/gasoline)] * (gasoline price) * (travel time)

Since the distances cancel each other in the first part of the formula, the term in parenthesis shows the gasoline expenditure per hour, which multiplied by the travel time and by the gasoline price equals the cost of the trip.

The average speed is calculated for some hours during the day by the Traffic Engineer Company (CET) annually. In the year of 2007, the average speed was 17 km/hour between 5AM and 8AM hours and 14.2 km/hour between 5PM and 7PM. In order to obtain the average speed in other periods of the day, the average speed for all periods for the trips of the Origin-Destination Survey were calculated. Then, the relationship between the values available in the CET research and the values calculated with the Origin-Destination data was used to calculate the average speed for the remaining periods (between 12AM and 1PM and the rest of the day).

The relationship between distance and gasoline usage is calculated since 2009 for a range of the most popular cars in Brazil by the National Institute of Metrology, Quality and Technology (Inmetro)[3]. These relationships were pondered by the number of each model of car sold in São Paulo state between 2002 and 2007, data available by Fenabrave[4].

The mean of the Gasoline price in the city of São Paulo for each month of 2007 is available by the National Agency of Petroleum, Natural gas and biofuels (ANP). The travel time is available at the Origin Destination Survey, computed as the difference between departure and arrival time

Motorcycle

The same formula was applied. The only difference between the cost of motorcycle and car trips is the relationship between the distance and the gasoline usage. In the case of motorcycle, this number was calculated by the pondered mean of the fuel efficiency of the seven models of motorcycle more common in the Brazilian roads, which sum 81.5% of the total motorcycles. The efficiency is available in specialized websites.

Inter municipal bus

The price of inter municipal bus trips are available in the Metropolitan Urban Transports Enterprise of São Paulo (EMTU) web site (www.emtu.sp.gov.br). In some cases, there are different prices for the same trip. In such cases, the mode of the relevant prices was considered. In the cases in which this criterion resulted in more than one value, the lower one was considered.

[3] http://www.inmetro.gov.br/consumidor/pbe/veiculos_leves.pdf
[4] http://www.fenabrave.org.br/principal/home/?sistema=conteudos|conteudo&id_conteudo=24#conteudo

Not all trip prices were available for 2007. In these cases, the price of 2012 was discounted by the relation between the mean prices of 2007 and 2012 for each region city (e.g.: for the case of the travel from Osasco to Taboão da Serra, the relationship between the mean price of the trips from the region of Osasco in 2007 was divided by the mean price of the same trips in 2012 and then multiplied by the price of 2012 of the trip between the cities). However, there were cases in which the travel in the Origin Destination Survey did not have a correspondent price in the EMTU website. In such cases the price considered was the mean price of the trips with departure from the same city.

Subway, train and municipal bus

According to the Metropolitan trains company of São Paulo, the ticket for the subway and the train usage in 2007 cost R$ 2.30. The same price is charged for the municipal bus usage in São Paulo. In the case of the „bilhete único[5]" the price charged was R$ 3.50 in 2007.

Hired bus

The price of the trips made by hired bus was calculated considering the cost of R$ 1.4/km divided by 10, which is the number of passengers considered. The price per distance is the one charged by one important enterprise of the sector [6].

Taxi

The prices of Taxi trips are available in the official website of the prefecture of São Paulo[7]. The document contains the price charged for hours of trip in the year of 2007.

5.4 – Travel time and cost matrices

Another important part of the database preparation is the time and the cost related to options that were not chosen but were available to the decision maker. Since these values

[5] "Bilhete único" is a ticket that allows the passenger to use up to 4 public transportation modes in the period of three hours and pay only one price for all these trips.

[6] http://www.translinevan.com.br/precos

[7] http://www3.prefeitura.sp.gov.br/cadlem/secretarias/negocios_juridicos/cadlem/integra.asp?alt=01122006D%20479360000

influence directly the results, this part of the data preparation deserves special attention. Two different approaches and its combination were considered to calculate the time and the cost that would be expended in trips that did not actually happen. The choice among the methodologies was done considering the adequacy of the Logit estimation results.

All methodologies are based on the information of trips that indeed happened and are present in the Origin-Destination survey. They differ from each other in the treatment of this information.

The first methodology calculated the predicted value of the trips by a regression model using the values of the trips that actually happened. Two different regressions were estimated, one with travel time as the dependent variable and other with trip costs as the dependent variable. Both consider the relationship of these dependent variables with distance, transportation mode and departure hour of the trip, variable that can be really important especially for travel time since the traffic varies considerably during the day and this may lead to slower trips during specific hours. The relationship between the dependent variables and the distance were expressed by a cubic equation. Both transportation mode and departure hour of the trip were included as dummies.

In the second approach, the mean time and the mean cost of the trips made with same origin and destination (considering the 460 different zones described in the survey) that were actually made were considered as the time and cost of the options that were not chosen. For instance, the mean price of the trips made by car inside Biritiba-Mirim (one of the 460 zones) was considered as the price of the option car for people that used other transportation mode to travel in the same region and had this option available in the choice set. For the cases that this procedure has generated missing values the same procedure was applied but considering the municipal divisions. This increases the number of trips with the same origin and destination, but probably generates means less close to the real value that time and cost would have. Even though these procedures include a large part of the database, there are some cases with missing values. These missing values were deleted since they do not represent relevant options in the choice set.

The third approach used the mean time and the mean cost of the trips with same origin and destination considering the 460 zone like in the second approach. Then, instead of consider the mean values of the trips between the 39 municipals for the missing values, the regression model used in first approach was applied to calculate the remaining values.

Both first and third approaches generated undesirable Logit estimated results. In both cases the time and cost coefficients were positive, which does not make sense since these coefficients indicates the disutility of longer and more expansive trips. The second approach generated more reasonable costs coefficients. However, the time coefficients were also positives in some cases. This problem will have more attention in the econometric results presentation.

5.5 – Trip motives

The survey includes trips with different motives. Since trips with different motives have distinct characteristics, which make the relationship between the choices made and the relevant variables be different for each group, usually the studies of transportation choice model consider trips only with work purpose.

n the Origin-Destination survey the trips have ten different purposes. Their frequency and share of the total of the trips are presented in Table.

Naturally, the most common origin and destination of the trips is home. n this kind of trips, the motivation of the origin or destination may be any of the other nine options, which make the motivations of the trips too different to be considered in the same model.

n the Logit estimation models, the three kinds of trips related to work will be considered. Together, these are the motives sum 4 % of the trips present in the survey. Trips made with educational purposes are also an important part of the survey, with 8.6% of the trips. The trips with educational purpose will be estimated with a similar approach of the one applied in the model of work trips in order to analyze if in fact there is an important difference in the relationship of the variables and the alternatives for trips with different purposes.

Table 3 - Trip Purposes

Trips Purpose	Origin Frequency	%	Destination Frequency	%
Work/industry	12,324	2.22	12,439	2.24
Work/business	22,163	4	22,853	4.12
Work/services	82,652	14.9	82,277	14.84
Education	103,061	18.58	103,833	18.72
Shopping	17,189	3.1	16,966	3.06
Healthy care	12,250	2.21	12,197	2.2
Leisure	17,728	3.2	18,191	3.28
Home	247,902	44.7	246,351	44.42
Search for job	798	0.14	790	0.14
Personal issues	38,473	6.94	38,643	6.97

Source: Origin and Destination Survey, São Paulo (2007)

5.6 – Econometric Results

The first part of the econometric analysis is the Multinomial Logit estimation. The most common variables considered in transportation mode choice are explicit costs and time. Regarding the individual characteristics, other important variables to be considered are income and car ownership, variable included as a dummy. The literature shows that in some cases it is also important to include demographic variables. Age, sex and household size were included in the models estimated for work and educational trips. However, the inclusion of these variables in the work trips model has led to positive coefficients of cost and time. In the case of educational trips, the inclusion of household size only has led to improvements in the estimation. Therefore, the models estimated for work trips consider only cost, time, income and car ownership as explainable variables and the models estimated for educational trips consider these variables and also household size.

The base alternative used to compare the specific to alternatives coefficients is the option Taxi. The complete list of alternatives is repeated here for convenience:

1 - Bus
2 - Subway
3 - Train
4- Driving
5- Shared Ride
6- Taxi
7- Motorcycle
8- Walking/bike
9- Any combination of bus, subway and train

Multinomial Logit

The first estimation procedure applied is the Multinomial Logit. The results of these estimations are presented in Table 17 in the Appendix.

Costs coefficients are negatives and significant for both models. However, the coefficient calculated for educational trips is considerably higher in absolute value. This indicates that the cost is more important for education trips. It is expected work trip demands to be less travel cost elastic.

The time coefficients do not have the expected value for work trips. As mentioned in section 5.3, this is related to the construction of the time matrix. The time that would be expended in trips which did not actually happen is problematic for the work trip as a closer look in the data indicates. Considering educational trips, the mean time of trips that really happened is 25.1 and the mean time of the trips with modes that were not chosen is 23.1. In the case of work trips, the mean time is 44.1 for trips that indeed happened and 29.1 for the options that were available but were not chosen. Therefore, the difference between the values is much higher for the work trips groups and indicates that the individuals have chosen trips that expend more time, which indicates that time does not affect negatively the decision process. This is counter intuitive and contrary to the literature results. However, all procedures applied to calculate cost and time of trips with modes that were not chosen lead to undesirable results like these.

In the case of the educational trips this problem did not happen, and the time coefficient is negative and significant.

Regarding the income coefficients for work trips, it is important to notice that the coefficients presented are all negative because the alternative chosen to be the base is taxi, an alternative very expensive and therefore with a strong positive relationship with income. Car does not have a significant negative coefficient. Since this option is also positively related with income, this result is very reasonable. Walking also does not have a significant coefficient. This may be related to the fact that 58% of the trips are shorter than 2km. Therefore, many individuals may choose to walk because the distance is short and the increase of income may not affect the option for this mode transportation.

All other options have negative and significant coefficients for work trips. Regarding public transportation modes, the four options have similar coefficients. The only two options that have statistically different coefficients are subway and train. A higher income makes the individual more likely to choose subway instead of train.

For the educational trips, the personal income does not have a significant impact in general. This may happen because trips made to educational purpose may be more related to the household income than to the personal income, since in many cases the students does not have their own personal income.

Regarding the car ownership, all coefficients are positive and significant for work trips. This is in accordance with the previous expectations, since the individual which has a car probably will not choose taxi as the transportation mode. Naturally, car is the option with the higher coefficient. Walking also has a high coefficient.

For educational trips, all car ownership coefficients are less significant. Since 20% of the individuals in the survey are 18 or fewer years old, the car ownership may not indicate that the individual can actually use it. The mean age of the individuals who travel for education purpose is 21, while the mean age of the individual who travel for all other reasons but education is 38. Therefore, it is expected that in many cases the individual may have a car available in his house but his age does not allow him to use it, which makes the car ownership not very important for the model choice for this kind of trips.

The household size lead to positive time and cost coefficients in the estimation of the work trip model and for this reason the model presented does not consider this variable. For the educational trips, this problem did not happen, but the inclusion of this variable did not increase considerably to the explanatory power of the model since for almost all alternatives the coefficients are not significant. The only significant coefficients indicates that the higher the family is, the higher is the chance of the trip with educational purpose be made by bus or by walking/bike.

So far, the results show that there is a strong difference between the relationship of the variables and the choice model for the trips with different purposes. For instance, the household income probably would lead to better results in the educational trips model, but the personal income has generated good results for the work trip models. Therefore, it is in fact important to consider the purpose of the trips in choice models estimation.

The elasticities – own price and cross-price – are presented in the table on the next page:

Table 4 - Elasticity Matrix - Multinomial Logit/Work Related Trips

Multinomial Logit		Percentage Change in Probability of Choosing								
Work Related Trips		Bus	Subway	Train	Driving	Shared Ride	Taxi	Motorcycle	Walking/Bike	Combined Public Transportation
Change by 1% in the cost of	Bus	-0.0673	0.0115	0.0153	0.0159	0.0145	0.0124	0.0162	0.0143	0.0195
	Subway	0.0017	-0.0802	0.0016	0.0019	0.0015	0.0022	0.0009	0.0019	0.0025
	Train	0.0002	0.0002	-0.0876	0.0002	0.0002	0.0001	0.0001	0.0002	0.0007
	Driving	0.0217	0.0229	0.0214	-0.0352	0.0229	0.0213	0.0160	0.0138	0.0296
	Shared Ride	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Taxi	0.0041	0.0044	0.0010	0.0039	0.0044	-0.5713	0.0042	0.0043	0.0026
	Motorcycle	0.0007	0.0002	0.0003	0.0006	0.0006	0.0006	-0.0152	0.0007	0.0007
	Walking/Bike	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Combined Public Transportation	0.0101	0.0073	0.0293	0.0084	0.0067	0.0043	0.0087	0.0057	-0.1413

Table 5 - Elasticity Matrix - Multinomial Logit and Educational Related Trips

Multinomial Logit		Percentage Change in Probability of Choosing								
Education Related Trips		Bus	Subway	Train	Driving	Shared Ride	Taxi	Motorcycle	Walking/Bike	Combined Public Transportation
Change by 1% in the cost of	Bus	-0.5726	0.0976	0.1107	0.1100	0.0978	0.1070	0.1034	0.0834	0.1383
	Subway	0.0080	-0.9372	0.0008	0.0109	0.0082	0.0095	0.0038	0.0070	0.0134
	Train	0.0005	0.0001	-1.1518	0.0004	0.0004	0.0006	0.0002	0.0003	0.0017
	Driving	0.0484	0.0821	0.0320	-0.4511	0.0539	0.0640	0.0360	0.0327	0.0674
	Shared Ride	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Taxi	0.0024	0.0020	0.0120	0.0027	0.0028	-6.0667	0.0029	0.0026	0.0023
	Motorcycle	0.0009	0.0005	0.0004	0.0009	0.0008	0.0010	-0.1634	0.0007	0.0014
	Walking/Bike	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Combined Public Transportation	0.0261	0.0412	0.0529	0.0288	0.0197	0.0179	0.0186	0.0128	-1.8844

Source: Authors‟ Estimates

The elasticities on the previous pages were computed from the percentage difference in the choice probabilities from increasing in 1% the cost of each trip time. The rows for walking and shared ride are composed of zeros because the explicit cost of this trip is zero.
The most striking feature for these tables is the marked difference between the elasticities for the work related trips and those for education related trips, with the latter being about ten times larger than the former. This result is related to the differences in the cost variable presented in the previous table, and will repeat itself on the other models, as we can see below.

Nested Logit

In order to deal with the known problem of Independence of Irrelevant Alternatives, the Nested Logit (NL) model groups alternatives which characteristics are expected to be stronger substitutes to each other.

Usually the number of possible nesting alternatives is large. However, the alternatives themselves allow certain nests to be ruled out as implausible. The nesting structure could be refined by using previous expectations and statistical tests.

The empirical validation of the nesting structures chosen is given by the dissimilarity parameter, also called nesting coefficient or logsum parameter. This statistical value is used to analyze the substitution pattern among alternatives of the same group. If its value is above 1 or below 0, it means that it is not consistent with the Random Utility Framework. Decreasing values in this range indicate increased substitution among alternatives inside the nest (Koppelman and Blat, 2006).

Different nesting structures were considered and two were selected with the best dissimilarity parameter. The nest that considers bus, train and subway in the same nest (public), driving and taxi in the same nest (car) and all other alternatives considered without any nest lead to the best results for the work trips. In the case of the educational trips, in all nesting structures at least one group presented dissimilarity parameter above one, which means model inadequacy. However, the model with best results will also be presented. Its nest structure differs from the work trip nesting structure only for considering shared ride also in the car group together with driving and taxi options (in the case that this option was not considered in this nest the dissimilarity parameters were even worse).

The nested logit results are presented in Table 18. The first important difference between the nested model results and the multinomial results is the cost coefficient. In the nested coefficient it is three times smaller in absolute value for work trips. The time coefficient is positive again. For the educational trips the values are very similar for the Multinomial and Nested Logit models.

Regarding the income effects, the coefficients are almost the same in both multinomial and nested models for work trips. For educational trips, the results must not be considered since the nested structure invalidates the model.

For the car ownership there is an important difference between the coefficients estimated for the nested model. Considering the significance level of 0.1%, the only significant coefficients are for the driving and walking option. This result makes sense, since the individuals who does not own a car may use any other option. It is important to notice again that the walking option is usually chosen because there are a great number of short distance trips. Its relationship with car ownership may indicate that even though the individual owns a car, he will be willing to walk or ride a bike if the trip is short.

Finally, the dissimilarity parameters show that the individual is more likely to change between car and taxi than change among public transportation modes. This is expected, since in some cases the individual does not have two different options of public transportation mode to make one specific trip.

The elasticities for both trip types are on the following pages:

Table 6 - Nested Logit - Work Related Trips

Nested Logit		Percentage Change in Probability of Choosing								
Work Related Trips		Bus	Subway	Train	Driving	Shared Ride	Taxi	Motorcycle	Walking/Bike	Combined Public Transportation
Change by 1% in the cost of	Bus	-0.0157	0.0042	0.0064	0.0037	0.0034	0.0030	0.0038	0.0034	0.0045
	Subway	0.0007	-0.0205	0.0006	0.0004	0.0003	0.0005	0.0002	0.0004	0.0006
	Train	0.0001	0.0001	-0.0238	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002
	Driving	0.0050	0.0053	0.0050	-0.0087	0.0053	0.0426	0.0037	0.0032	0.0069
	Shared Ride	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Taxi	0.0011	0.0016	0.0001	0.0105	0.0010	-0.5552	0.0011	0.0010	0.0008
	Motorcycle	0.0002	0.0000	0.0001	0.0001	0.0001	0.0001	-0.0035	0.0002	0.0002
	Walking/Bike	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Combined Public Transportation	0.0024	0.0017	0.0070	0.0020	0.0016	0.0010	0.0021	0.0014	-0.0323

Source: Authors" Computations

Table 7 - Nested Logit - Education Related Trips

Nested Logit		Percentage Change in Probability of Choosing								
Education Related Trips		Bus	Subway	Train	Driving	Shared Ride	Taxi	Motorcycle	Walking/Bike	Combined Public Transportation
Change by 1% in the cost of	Bus	-0.5845	0.1088	0.1332	0.1081	0.1178	0.1038	0.1016	0.0819	0.1577
	Subway	0.0089	-0.9695	0.0009	0.0107	0.0094	0.0090	0.0037	0.0068	0.0144
	Train	0.0005	0.0001	-1.2117	0.0004	0.0005	0.0006	0.0002	0.0003	0.0020
	Driving	0.0480	0.0819	0.0325	-0.4429	0.0534	-0.0974	0.0359	0.0325	0.0667
	Shared Ride	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Taxi	0.0043	0.0049	0.0149	-0.0317	0.0050	-3.8097	0.0057	0.0046	0.0041
	Motorcycle	0.0009	0.0005	0.0004	0.0009	0.0008	0.0010	-0.1617	0.0007	0.0014
	Walking/Bike	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Combined Public Transportation	0.0294	0.0442	0.0584	0.0284	0.0227	0.0173	0.0180	0.0124	-1.9723

Source: Authors‟ Computations

The differences between the elasticities for both types of trip are still quite large, although not as large as in the case of the multinomial logit. The own price elasticity for the taxi transport mode, which was more than ten times larger for the education trips than for work related trips in the multinomial logit model, now are only about six times larger.

Mixed Logit

The Mixed Logit, as the Nested Logit, is not affected by the IIA property and therefore presents more reliable results. One important feature of this model is that it is allowed for the researcher to consider that the coefficients may vary among individuals, which means that it allows for random taste variation and unrestricted substitution patterns.

It was considered that the cost and the time could have this pattern, but the models which consider this property only for the time presented better results both for work and education trip models.

The results of these models are presented in Table 8. We assumed in the estimates below the unobserved heterogeneity to be present in the trip time variable, in which it is distributed according to a standard normal. The choice probability integral was computed by Monte Carlo Integration, using 50 Halton draws[8].

The results are almost identical of the ones obtained for the Multinomial Logit model for trips with both purposes, which is previously expected since the only variable allowed to have coefficient with random pattern is time. The most relevant difference is that in the case of educational trips, the travel time (sd) coefficient is higher than the travel time coefficient, which indicate that this coefficient can be positive for some individuals and that there may be a problem in the time calculated for the modes that were not chosen also for educational trips.

[8] We used the ado-file "mixlogit" from Stata, from Hole (2007)

Table 8 - Mixed Logit

	Work Trips		Educational Trips	
	Coef	**Sd**	**Coef**	**Sd**
Cost	-0.04588***	(0.01)	-0.49714***	(0.03)
Travel time	0.00710***	(0.00)	-0.03364***	(0.00)
Travel time (sd)	0.00027	(0.00)	-0.04447***	(0.00)
Personal Income				
Bus	-0.00023***	(0.00)	-0.00059*	(0.00)
Subway	-0.00019***	(0.00)	-0.00003	(0.00)
Train	-0.00069**	(0.00)	0.00035	(0.00)
Driving	-0.00004	(0.00)	0.00061**	(0.00)
Shared Ride	-0.00072***	(0.00)	-0.00109***	(0.00)
Motorcycle	-0.00033***	(0.00)	0.00054*	(0.00)
Walking/bike	-0.00002	(0.00)	-0.00076**	(0.00)
Combination (Public)	-0.00029***	(0.00)	0.00023	(0.00)
Car Ownership				
Bus	1.81589***	(0.17)	-2.15838*	(1.08)
Subway	1.75005***	(0.19)	-2.05448	(1.10)
Train	1.51780***	(0.42)	-0.16651	(1.24)
Driving	2.23272***	(0.16)	-0.83755	(1.08)
Shared Ride	1.82614***	(0.17)	-1.04036	(1.08)
Motorcycle	1.34251***	(0.18)	-2.36794*	(1.10)
Walking/bike	2.26735***	(0.17)	-2.77669**	(1.08)
Combination (Public)	1.42730***	(0.18)	-2.09357	(1.09)
Household size				
Bus			0.53565*	(0.22)
Subway			0.39869	(0.23)
Train			-0.45603	(0.27)
Driving			-0.22968	(0.22)
Shared Ride			-0.03154	(0.22)
Motorcycle			-0.42737	(0.23)
Walking/bike			0.67527**	(0.22)
Combination (Public)			0.40666	(0.22)
Log-likelihood	-9663027		-9391314	
Chi-Squared	2084		6440	

OBS: *** - Significant at 0.1%, ** - Significant at 1% * - Significant at 5%.

The main point from the results above is that the high degree of heterogeneity on the time coefficients, which could be one of the reasons for the persistent positive coefficients for the time variable on the other specifications. The own and cross-price elasticities are on the next tables:

Table 9 - Mixed Logit - Work Related Trips

Mixed Logit		Percentage Change in Probability of Choosing								
Work Related Trips		Bus	Subway	Train	Driving	Shared Ride	Taxi	Motorcycle	Walking/Bike	Combined Public Transportation
Change by 1% in the cost of	Bus	-0.0674	0.0115	0.0153	0.0159	0.0145	0.0124	0.0162	0.0143	0.0195
	Subway	0.0017	-0.0802	0.0016	0.0019	0.0015	0.0022	0.0009	0.0019	0.0025
	Train	0.0002	0.0002	-0.0876	0.0002	0.0002	0.0001	0.0001	0.0002	0.0007
	Driving	0.0217	0.0229	0.0214	-0.0352	0.0229	0.0213	0.0160	0.0138	0.0296
	Shared Ride	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Taxi	0.0041	0.0044	0.0010	0.0039	0.0044	-0.5713	0.0042	0.0043	0.0026
	Motorcycle	0.0007	0.0002	0.0003	0.0006	0.0006	0.0006	-0.0152	0.0007	0.0007
	Walking/Bike	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Combined Public Transportation	0.0101	0.0073	0.0293	0.0084	0.0067	0.0043	0.0087	0.0057	-0.1413

Source: Authors‟ Computations

Table 10 - Mixed Logit/Education Related Trips

Mixed Logit		Percentage Change in Probability of Choosing								
Education Related Trips		Bus	Subway	Train	Driving	Shared Ride	Taxi	Motorcycle	Walking/Bike	Combined Public Transportation
Change by 1% in the cost of	Bus	-0.5300	0.1016	0.1426	0.1041	0.0921	0.1149	0.1001	0.0792	0.1536
	Subway	0.0077	-0.9014	0.0014	0.0104	0.0079	0.0090	0.0042	0.0065	0.0119
	Train	0.0007	0.0001	-1.0111	0.0004	0.0004	0.0003	0.0001	0.0003	0.0028
	Driving	0.0447	0.0768	0.0256	-0.4445	0.0540	0.0635	0.0356	0.0313	0.0550
	Shared Ride	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Taxi	0.0023	0.0019	0.0106	0.0029	0.0031	-6.1243	0.0032	0.0026	0.0016
	Motorcycle	0.0009	0.0005	0.0003	0.0009	0.0008	0.0011	-0.1635	0.0007	0.0012
	Walking/Bike	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Combined Public Transportation	0.0313	0.0354	0.1391	0.0245	0.0174	0.0150	0.0161	0.0122	-1.5828

Source: Authors‟ Computations

The results of the previous tables are quite close to the ones of the multinomial Logit, probably due to the fact it is assumed here the coefficients for the cost variable to be fixed – that is, without heterogeneity.

Considering these estimates, the next section will be focused on the simulation exercises for the proposed policies.

6. Simulation Results

In this section, we discuss the traffic effects from some policies, considering all demand models presented before. More specifically, we discuss in this paper two different alternatives:

1. An increase in the reach of the current rotation system, in which cars with even last digits of the license plate are not allowed to circulate half of the week, in alternating weekdays. Cars with odd last digits of the license plate are not allowed to circulate the other half of the week. Cars that do not conform to this policies are subject to the current fine for violating the rotation system, of about 127.69 BRL
2. The introduction of the urban congestion tax of about 12.00 BRL[9].

We are assuming only trips by car – and not shared car – are subject to the rotation restrictions (thus, we are implicitly assuming people who engage in sharing rides are able to choose cars with the correct license plate to evade the fines). Evidently, both car and share ride are subject to the urban congestion tax.

The table below shows the results for the extension of the rotation system, for both types of trips – education and work, for the mixed logit model. Analogous results for the other models can be found at the Appendix.

[9] The current subway fare for São Paulo is 3.00 BRL.

Table 11 - Expanded Rotation - Mixed Logit/Work Related Trips

Mixed Logit		Expanded Rotation									
Work Related Trips		Bus	Subway	Train	Driving	Shared Ride	Taxi	Motorcycle	Walking/Bike	Combined Public Transportation	Total
Status quo	Bus	5.133%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	5.133%
	Subway	0.000%	2.308%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	2.308%
	Train	0.000%	0.000%	0.002%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.002%
	Driving	15.045%	4.724%	0.048%	3.006%	4.838%	0.765%	0.604%	4.325%	4.530%	37.885%
	Shared Ride	0.000%	0.000%	0.000%	0.000%	0.367%	0.000%	0.000%	0.000%	0.000%	0.367%
	Taxi	0.000%	0.000%	0.000%	0.000%	0.000%	0.027%	0.000%	0.000%	0.000%	0.027%
	Motorcycle	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.289%	0.000%	0.000%	0.289%
	Walking/Bike	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	52.010%	0.000%	52.010%
	Combined Public Transportation	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	1.980%	1.980%
	Total	20.178%	7.032%	0.051%	3.006%	5.205%	0.792%	0.893%	56.335%	6.510%	100.000%

Source: Authors‟ Computations

Table 12 - Mixed Logit - Expanded Rotation and Education Trips

Mixed Logit		Congestion Charge									
Education Related Trips		Bus	Subway	Train	Driving	Shared Ride	Taxi	Motorcycle	Walking/Bike	Combined Public Transportation	Total
Status quo	Bus	9.739%	0.013%	0.000%	0.000%	0.070%	0.000%	0.000%	0.048%	0.013%	9.883%
	Subway	0.000%	1.890%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	1.890%
	Train	0.000%	0.000%	0.009%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.009%
	Driving	3.343%	1.300%	0.012%	0.829%	2.262%	0.199%	1.412%	4.508%	1.566%	15.431%
	Shared Ride	0.010%	0.000%	0.000%	0.000%	11.137%	0.000%	0.000%	0.000%	0.000%	11.147%
	Motorcycle	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.184%	0.000%	0.000%	0.184%
	Walking/Bike	0.000%	0.000%	0.000%	0.000%	0.165%	0.000%	0.000%	60.631%	0.000%	60.796%
	Combined Public Transportation	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.660%	0.660%
	Total	13.092%	3.204%	0.021%	0.829%	13.633%	0.199%	1.596%	65.188%	2.239%	100.000%

Source: Authors" Computations

The results for the tables above show interesting effects. In the first place, an extension of the rotation system tends to cause an important shift from driving to the busing system in the case of work trips. This result is quite robust and tends to be present regardless of the econometric model used. For education trips, the expanded rotation system seems to have a lower effect of shifting from driving to the bus system (only in the case of the Mixed Logit Model we have similar effects for educational trips as to the work trips).

For the case of the congestion tax under the specifications above, the results are as follows:

Table 13 - Work Related Trips - Congestion Charge and Mixed Logit

Mixed Logit		Congestion Charge									
Work Related Trips		Bus	Subway	Train	Driving	Shared Ride	Taxi	Motorcycle	Walking/Bike	Combined Public Transportation	Total
Status quo	Bus	5.133%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	5.133%
	Subway	0.000%	2.308%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	2.308%
	Train	0.000%	0.000%	0.002%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.002%
	Driving	15.623%	4.754%	0.048%	2.208%	4.838%	0.782%	0.604%	4.399%	4.629%	37.885%
	Shared Ride	0.000%	0.000%	0.000%	0.000%	0.325%	0.000%	0.000%	0.000%	0.042%	0.367%
	Taxi	0.000%	0.000%	0.000%	0.000%	0.000%	0.027%	0.000%	0.000%	0.000%	0.027%
	Motorcycle	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.289%	0.000%	0.000%	0.289%
	Walking/Bike	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	52.010%	0.000%	52.010%
	Combined Public Transportation	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	1.980%	1.980%
	Total	20.756%	7.062%	0.051%	2.208%	5.162%	0.808%	0.893%	56.409%	6.651%	100.000%

Source: Author"s Computations

Table 14 - Mixed Logit, Education Related Trips and Congestion Charge

Mixed Logit		Congestion Charge									
Education Related Trips		Bus	Subway	Train	Driving	Shared Ride	Taxi	Motorcycle	Walking/Bike	Combined Public Transportation	Total
Status quo	Bus	9.739%	0.013%	0.000%	0.000%	0.070%	0.000%	0.000%	0.048%	0.013%	9.883%
	Subway	0.000%	1.890%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	1.890%
	Train	0.000%	0.000%	0.009%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.009%
	Driving	3.620%	1.317%	0.012%	0.342%	2.158%	0.217%	1.410%	4.620%	1.736%	15.431%
	Shared Ride	0.709%	0.039%	0.020%	0.000%	10.157%	0.000%	0.000%	0.060%	0.163%	11.147%
	Motorcycle	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.184%	0.000%	0.000%	0.184%
	Walking/Bike	0.002%	0.000%	0.000%	0.000%	0.099%	0.000%	0.000%	60.695%	0.000%	60.796%
	Combined Public Transportation	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.660%	0.660%
	Total	14.069%	3.259%	0.041%	0.342%	12.484%	0.217%	1.594%	65.423%	2.572%	100.000%

Source: Author"s Computations

The columns represent the traffic breakdown across the different modes under the counterfactual, and the rows represent the traffic allocation observed. In both cases, respecting the sampling scheme of the original microdata, Thus, the elements off diagonal in the table above and in the appendix tables represent changes from moving from the existing traffic arrangements to each of the proposed policies – either expanded rotation system or congestion charge.

The results for the congestion charge seem to indicate it is to be expected a lower shift from driving to other public transportation methods, regardless of whether the trip is work or education related. Only for the case of the Mixed Logit model one does find a larger shift from driving to public transportation modes.

As for the most important substitution patterns noticed throughout the tables, it seems the most important shift is from driving to public transportation modes.
This probably have effects on the traffic and pollution of São Paulo city, since they tend to be less pollutant and could reduce the number of cars in the streets leading to the expanded center.

Another measurement of alternative policies is the Logsum measure, an approximation of the expected Consumer Surplus. For the multinomial Logit, we have the following form:

$$E(CS_i) = \frac{\ln(\sum e^{\delta_{ij}})}{\alpha_i} + C$$

In which the term C is a constant which would not be used in the computation, and α_i would be the marginal effect on utility from a marginal increase in the cost of the alternative. For the Nested Logit, the Logsum measure is as follows:

$$E(CS_i) = \frac{\ln\left(\sum_h \left(\sum_{j\in h} e^{\delta_{ij}}\right)^{\sigma}\right)}{\alpha_i} + C$$

In this equation, the σ parameter measure the correlation between the ε"s (the idiosyncratic part of utility – which gives its character of random utility choice) of alternatives in the same nest, and the first summation – over h -- computes the sum over different nests.

And finally, the consumer surplus from the mixed Logit model is computed by the following:

$$E(CS_i) = \int \frac{\ln\left(\sum e^{\delta_{ij}+\sigma_i v_i z_{ni}}\right)}{\alpha_i} dP(v) + C$$

In which the integration is carried out over the distribution of the unobserved characteristics.

Given the values computed for the status quo and alternative policies, we could compute the differences in expected consumer surplus from imposing further restrictions in the rotation system and from the congestion charge. These formulas were applied to derive the welfare effects from each policy[10]. The results are presented below:

Table 15 - Average (across individuals) of Differences in Expected Consumer Surplus

Model	Trips	$E(CS_R) - E(CS_0)$	$E(CS_{CT}) - E(CS_0)$
Multinomial	Work Related	-2.69320	-2.34820
Nested	Work Related	-6.48110	-2.33220
Mixed	Work Related	-1.96750	-3.83890
Multinomial	Education Related	-0.08466	-1.05070
Nested	Education Related	-2.85400	-1.10520
Mixed	Education Related	-0.06334	-0.95568

In which $E(CS_R)$ pertains to the expected consumer surplus from the expanded rotation system, $E(CS_0)$ the consumer surplus under the status quo, and $E(CS_{CT})$ the expected consumer surplus from the congestion charge.

All values in the table above are negative, which is consistent with the fact in both cases it is imposed an increase in costs for some trips. Thus, the selection would be on the policy alternative which would be least costly in terms of consumer surplus.

The results above indicate that, for education trips, the extension of the rotation system would have a lower loss of consumer surplus than the congestion charge (both Multinomial and Mixed Logit would point in the same way. The nested Logit for this sort of trip has some problem with the underlying nesting structure).

[10] In the case of the Mixed Logit, the integral was computed by simulation using a set of Halton Draws.

For work trips, the results are not that clear, with Multinomial and Nested Logit pointing to a superiority of the Congestion Charge over the Expanded Rotation System, and the Mixed Logit pointing at the opposite direction.

At this point, some comments are in order. The Consumer Surplus measures presented above are a very narrow measure of welfare effects from each proposed policy, and it is important to make clear what these numbers intend to measure and what they do not intend to measure.

The above measure of Consumer Surplus intend only to provide a monetary measure of the loss of welfare from increase travel costs, everything else held constant. With this measure we do not intend to capture the effects on welfare from decreased congestion in the expanded center, neither the effects from the overuse of existing traffic infrastructure due to large shifts in travel patterns. We also do not intend to measure the pollution effects from the increased usage of public transportation systems, nor the effects on traffic accidents.

All these effects could be studied by including relations – either econometrically estimated or computed from simulation of the transportation grid network – between the demand estimates and these variables. However, this will be left to future work.

Finally, we could estimate a measure of government revenues from the congestion charge, expressed as a percentage of the revenues from the existing rotation system. The table below presents these values:

Table 16 - Revenues as a percentage of revenues from rotation system

Model	Trips	Revenues
Multinomial	Work	16.53%
Nested	Work	17.57%
Mixed	Work	7.76%
Multinomial	Education	6.24%
Nested	Education	6.26%
Mixed	Education	6.11%

The results above indicate the congestion charge on top of existing rotation system tends to generate less than 20% of the revenues from the existing rotation system.

7. Conclusions

The present report presents the estimates of welfare and traffic effects of a congestion charge to be levied on automobiles in São Paulo. In order to do so, this study used the microdata of the Origin-Destination survey carried out by São Paulo"s subway company. As for methodology, this research will employ discrete choice methods (Logit, Nested Logit and Mixed Logit) to identify structural parameters. With these parameters, it was estimated the likely effects on traffic flows of imposing different types of congestion taxes. The estimated coefficients can also be used to estimate the welfare effects of such measures.

In this paper, it was used as a starting point for further research a very narrow definition of welfare, the consumer surplus from the increase in trip costs from each alternative. The effects on welfare from increased pollution or gridlock are not considered, because they would require embedding the models in a larger model considering the city transportation network.

As for the results, the models for the work related trips tend to generate very inelastic demands for each transportation mode. The demands for education trips tend to be much more elastic.

Section 4 presented some international experiences on congestion charging. Section 6 presented some simulations that aim to predict economic and traffic effects caused by the adoption of two different policies: (1) an increase in the reach of the existing rotation system and (2) the introduction of an urban congestion charge. In the present section we try to compare the real effects observed in Singapore, London and Stockholm with the predicted effects about Sao Paulo.

All of the three cities have reached their main objective of reducing congestion and keep it at lower levels. In Singapore, London and Stockholm traffic in the priced zone reduced around 10% to 30%, and that reductions were sustained over time. As consequence, travel's speed within the priced zone increased significantly. Additionally, in the three cities, up to 50% of those car travels through the priced zone have shifted to public transportation.

The simulations on Brazilian data showed similar results. The increase in the reach of the actual rotation system implied in a significant shift from car to bus travels, especially in the case of work trips. This result remained robust for all econometric models that were simulated. On the other hand, the simulations on congestion charging lead to a smaller shift from driving to other modes of public transportation modes. We believe the shift from car to collective travels tend to reduce traffic and raise the average travel's speed, such as observed in the international experiences.

In all of the three cities the revenues exceed the costs. In Singapore, revenues have been over 10 times the operating costs. In Stockholm and London the revenues have been over twice the costs. In these two cities, revenues are used mainly to recover operating and enforcement costs, although the original idea was to use revenues to improve public transportation. In Singapore, the great surplus of funds has allowed the government to implement new public transportation programs.

In Sao Paulo, the simulations consistently showed that the implementation of a new congestion charge tends to generate less than 20% of the expected revenues obtained by the increase of the actual rotation system. Once the actual rotation system is cheaper than an eventual congestion charge, this system is more profitable to the city.

The three cities have experienced a better environment as consequence of the smaller number of trips (and CO2 emissions) inside the charged zone. Besides the reduction in the number of trips, the increasing number of "green cars" has becoming the air quality even better. In Sao Paulo, once the bigger shift was from driving to public transportation modes, it certainly will impact positively on pollution.

Finally, the simulated welfare effects for the increase of the rotation system would have a lower loss of consumer surplus for education trips when compared to congestion charge. For work trips, the results are not conclusive.

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Appendix

Table 17 - Multinomial Logit Results

	Work Trips		Educational Trips	
	Coef	**Sd**	**Coef**	**Sd**
Cost	-0.04588***	(0.01)	-0.49226***	(0.02)
Travel time	0.00710***	(0.00)	-0.01032***	(0.00)
Personal Income				
Bus	-0.00023***	(0.00)	-0.00056*	(0.00)
Subway	-0.00019***	(0.00)	-0.00002	(0.00)
Train	-0.00069**	(0.00)	0.00024	(0.00)
Driving	-0.00004	(0.00)	0.00058**	(0.00)
Shared Ride	-0.00072***	(0.00)	-0.00108***	(0.00)
Motorcycle	-0.00033***	(0.00)	0.00051*	(0.00)
Walking/bike	-0.00002	(0.00)	-0.00076**	(0.00)
Combination (Public)	-0.00029***	(0.00)	0.00013	(0.00)
Car Ownership				
Bus	1.81595***	(0.17)	-2.25073*	(1.06)
Subway	1.75010***	(0.19)	-2.22754*	(1.08)
Train	1.51795***	(0.42)	-1.54662	(1.14)
Driving	2.23276***	(0.16)	-0.96533	(1.06)
Shared Ride	1.82619***	(0.17)	-1.14265	(1.06)
Motorcycle	1.34256***	(0.18)	-2.38821*	(1.08)
Walking/bike	2.26740***	(0.17)	-2.80077**	(1.06)
Combination (Public)	1.42739***	(0.18)	-2.13830*	(1.07)
Household size				
Bus			0.46504*	(0.22)
Subway			0.37542	(0.22)
Train			-0.13138	(0.23)
Driving			-0.22695	(0.22)
Shared Ride			-0.04135	(0.22)
Motorcycle			-0.41676	(0.22)
Walking/bike			0.62514**	(0.22)
Combination (Public)			0.39144	(0.22)
Log-likelihood	-9663030		-9455210	
Chi-Squared	2085		8581	

OBS: *** - Significant at 0.1%, ** - Significant at 1% * - Significant at 5%.

Table 18 - Nested Logit Results

	Work Trips		Educational Trips	
	Coef	Sd	Coef	Sd
Cost	-0.01056*	(0.00)	-0.48710***	(0.03)
Travel time	0.00609***	(0.00)	-0.00977***	(0.00)
Personal Income				
Bus	-0.00022***	(0.00)	0.00024	(0.00)
Subway	-0.00018***	(0.00)	0.00076	(0.00)
Train	-0.00066**	(0.00)	0.00098	(0.00)
Driving	-0.00003***	(0.00)	0.00139*	(0.00)
Shared Ride	-0.00069***	(0.00)	-0.00026	(0.00)
Motorcycle	-0.00032***	(0.00)	0.00132*	(0.00)
Walking/bike	-0.00001	(0.00)	0.00004	(0.00)
Combination (Public)	-0.00030***	(0.00)	0.00089	(0.00)
Car Ownership				
Bus	0.16229	(0.09)	1.07833	(0.60)
Subway	0.13349	(0.12)	1.11349	(0.63)
Train	-0.01881	(0.36)	1.77580*	(0.73)
Driving	0.56666***	(0.08)	2.37406***	(0.61)
Shared Ride	0.19938*	(0.10)	2.12251***	(0.61)
Motorcycle	-0.29129*	(0.12)	0.92349	(0.64)
Walking/bike	0.64318***	(0.09)	0.51063	(0.60)
Combination (Public)	-0.24367*	(0.11)	1.19303	(0.61)
Household size				
Bus			-0.04856	(0.12)
Subway			-0.1342	(0.13)
Train			-0.60405***	(0.15)
Driving			-0.74984***	(0.12)
Shared Ride			-0.53165***	(0.13)
Motorcycle			-0.92934***	(0.14)
Walking/bike			0.11255	(0.13)
Combination (Public)			-0.10923	(0.12)
Dissimilatiry par.				
car_tau	0.20542***	(0.03)	1.85970***	(0.19)
shared_ride_tau	1.00000**	(0.33)		
motorcycle_tau	1.00000***	(0.23)	1	(0.56)
public_tau	0.76085***	(0.10)	0.93861***	(0.05)
comb_tau	1.00000***	(0.20)		(1.99)
walking_tau	1.00000***	(0.12)	1	
Log-likelihood	-9644053		-9448106	
Chi-Squared	1727		6342	

OBS: *** - Significant at 0.1%, ** - Significant at 1% * - Significant at 5%.

Table 19 - Predicted mode Choice - Status Quo and Expanded Rotation System – Work Trips and Multinomial Logit

Multinomial Logit		Expanded Rotation									
Work Related Trips		Bus	Subway	Train	Driving	Shared Ride	Taxi	Motorcycle	Walking/Bike	Combined Public Transportation	Total
Status quo	Bus	5.136%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	5.136%
	Subway	0.000%	2.308%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	2.308%
	Train	0.000%	0.000%	0.002%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.002%
	Driving	15.030%	4.728%	0.046%	2.930%	4.806%	0.800%	0.645%	4.331%	4.571%	37.886%
	Shared Ride	0.000%	0.000%	0.000%	0.000%	0.367%	0.000%	0.000%	0.000%	0.000%	0.367%
	Taxi	0.000%	0.000%	0.000%	0.000%	0.000%	0.027%	0.000%	0.000%	0.000%	0.027%
	Motorcycle	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.289%	0.000%	0.000%	0.289%
	Walking/Bike	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	52.007%	0.000%	52.007%
	Combined Public Transportation	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	1.980%	1.980%
	Total	20.166%	7.036%	0.048%	2.930%	5.173%	0.826%	0.934%	56.338%	6.551%	100.001%

Table 20 - Expanded Rotation System/Multinomial Logit and Education Trips

Multinomial Logit		Expanded Rotation									
Work Related Trips		Bus	Subway	Train	Driving	Shared Ride	Taxi	Motorcycle	Walking/Bike	Combined Public Transportation	Total
Status quo	Bus	9.143%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	9.143%
	Subway	0.000%	1.911%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	1.911%
	Driving	3.328%	1.381%	0.019%	0.757%	1.886%	0.193%	1.472%	4.332%	1.517%	14.885%
	Shared Ride	0.000%	0.000%	0.000%	0.000%	10.251%	0.000%	0.000%	0.000%	0.000%	10.251%
	Motorcycle	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.098%	0.000%	0.000%	0.098%
	Walking/Bike	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	63.006%	0.000%	63.006%
	Combined Public Transportation	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.706%	0.706%
	Total	12.471%	3.292%	0.019%	0.757%	12.137%	0.193%	1.570%	67.338%	2.223%	100.000%

Table 21 - Expanded Rotation - Nested Logit and Work Related Trips

Nested Logit		Expanded Rotation									
Work Related Trips		Bus	Subway	Train	Driving	Shared Ride	Taxi	Motorcycle	Walking/Bike	Combined Public Transportation	Total
Status quo	Bus	5.029%	0.000%	0.000%	0.000%	0.000%	0.081%	0.000%	0.000%	0.000%	5.110%
	Subway	0.000%	2.252%	0.000%	0.000%	0.000%	0.031%	0.000%	0.000%	0.000%	2.283%
	Train	0.000%	0.000%	0.008%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.008%
	Driving	12.214%	3.879%	0.017%	11.401%	1.547%	2.138%	0.269%	5.014%	2.367%	38.846%
	Shared Ride	0.000%	0.000%	0.000%	0.000%	0.223%	0.002%	0.000%	0.000%	0.000%	0.225%
	Taxi	0.000%	0.000%	0.000%	0.000%	0.000%	0.283%	0.000%	0.000%	0.000%	0.283%
	Motorcycle	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.205%	0.000%	0.000%	0.205%
	Walking/Bike	0.000%	0.000%	0.000%	0.000%	0.000%	0.087%	0.000%	50.469%	0.000%	50.556%
	Combined Public Transportation	0.000%	0.000%	0.000%	0.000%	0.000%	0.042%	0.000%	0.000%	2.444%	2.485%
	Total	17.243%	6.130%	0.025%	11.401%	1.770%	2.663%	0.473%	55.483%	4.811%	100.001%

Table 22 - Expanded Rotation System/Nested Logit for Education Trips

Nested Logit		Expanded Rotation									
Education Related Trips		Bus	Subway	Train	Driving	Shared Ride	Taxi	Motorcycle	Walking/Bike	Combined Public Transportation	Total
Status quo	Bus	8.997%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	8.997%
	Subway	0.000%	1.911%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	1.911%
	Driving	3.503%	1.371%	0.011%	0.722%	1.892%	0.046%	1.469%	4.342%	1.492%	14.848%
	Shared Ride	0.000%	0.000%	0.000%	0.000%	10.310%	0.000%	0.000%	0.000%	0.000%	10.310%
	Motorcycle	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.098%	0.000%	0.000%	0.098%
	Walking/Bike	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	63.122%	0.000%	63.122%
	Combined Public Transportation	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.714%	0.714%
	Total	12.500%	3.282%	0.011%	0.722%	12.202%	0.046%	1.568%	67.464%	2.206%	100.000%

Table 23 - Congestion Charge - Work Related Trips/Multinomial Logit

Multinomial Logit		Congestion Charge									
Work Related Trips		Bus	Subway	Train	Driving	Shared Ride	Taxi	Motorcycle	Walking/Bike	Combined Public Transportation	Total
Status quo	Bus	5.136%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	5.136%
	Subway	0.000%	2.308%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	2.308%
	Train	0.000%	0.000%	0.002%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.002%
	Driving	0.879%	0.030%	0.000%	36.686%	0.000%	0.017%	0.000%	0.142%	0.132%	37.885%
	Shared Ride	0.000%	0.000%	0.000%	0.000%	0.325%	0.000%	0.000%	0.000%	0.042%	0.367%
	Taxi	0.000%	0.000%	0.000%	0.000%	0.000%	0.027%	0.000%	0.000%	0.000%	0.027%
	Motorcycle	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.289%	0.000%	0.000%	0.289%
	Walking/Bike	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	52.007%	0.000%	52.007%
	Combined Public Transportation	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	1.980%	1.980%
	Total	6.015%	2.338%	0.002%	36.686%	0.325%	0.043%	0.289%	52.149%	2.154%	100.000%

Table 24 - Congestion Charge/Education Related Trips/Multinomial Logit

Multinomial Logit		Congestion Charge									
Education Related Trips		Bus	Subway	Train	Driving	Shared Ride	Taxi	Motorcycle	Walking/Bike	Combined Public Transportation	Total
Status quo	Bus	9.143%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	9.1429%
	Subway	0.000%	1.911%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	1.9106%
	Driving	0.303%	0.025%	0.000%	14.024%	0.000%	0.004%	0.000%	0.193%	0.336%	14.8853%
	Shared Ride	0.559%	0.058%	0.020%	0.000%	9.451%	0.000%	0.000%	0.000%	0.162%	10.2510%
	Motorcycle	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.098%	0.000%	0.000%	0.0982%
	Walking/Bike	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	63.006%	0.000%	63.0060%
	Combined Public Transportation	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.706%	0.7065%
	Total	10.0054%	1.9939%	0.0203%	14.0240%	9.4507%	0.0039%	0.0982%	63.1991%	1.2049%	100.0005%

Table 25 - Congestion Charge - Work Related Trips and Nested Logit Model

Nested Logit		Congestion Charge									
Work Related Trips		Bus	Subway	Train	Driving	Shared Ride	Taxi	Motorcycle	Walking/Bike	Combined Public Transportation	Total
Status quo	Bus	5.110%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	5.110%
	Subway	0.000%	2.283%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	2.283%
	Train	0.000%	0.000%	0.008%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.008%
	Driving	0.110%	0.010%	0.000%	38.572%	0.000%	0.000%	0.000%	0.116%	0.037%	38.846%
	Shared Ride	0.000%	0.000%	0.000%	0.000%	0.205%	0.000%	0.000%	0.000%	0.020%	0.225%
	Taxi	0.000%	0.000%	0.000%	0.000%	0.000%	0.283%	0.000%	0.000%	0.000%	0.283%
	Motorcycle	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.205%	0.000%	0.000%	0.205%
	Walking/Bike	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	50.555%	0.000%	50.555%
	Combined Public Transportation	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	2.486%	2.486%
	Total	5.220%	2.293%	0.008%	38.572%	0.205%	0.283%	0.205%	50.671%	2.543%	100.000%

Table 26 - Nested Logit - Congestion Charge and Education Related Trips

Nested Logit		Congestion Charge								
Education Related Trips		Bus	Subway	Train	Driving	Shared Ride	Motorcycle	Walking/Bike	Combined Public Transportation	Total
Status quo	Bus	8.997%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	8.997%
	Subway	0.000%	1.911%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	1.911%
	Driving	0.303%	0.025%	0.000%	14.013%	0.000%	0.000%	0.193%	0.314%	14.848%
	Shared Ride	0.559%	0.058%	0.020%	0.000%	9.510%	0.000%	0.000%	0.162%	10.310%
	Motorcycle	0.000%	0.000%	0.000%	0.000%	0.000%	0.098%	0.000%	0.000%	0.098%
	Walking/Bike	0.014%	0.000%	0.000%	0.000%	0.000%	0.000%	63.108%	0.000%	63.122%
	Combined Public Transportation	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.714%	0.714%
	Total	9.873%	1.994%	0.020%	14.013%	9.510%	0.098%	63.301%	1.190%	100.000%