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# Policy Dilemma: Road Pricing or Road Space Rationing – Evidence from Santiago, Chile

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**Abstract**

Road pricing and emission taxes are economically efficient policies to deal with the two major urban transportation externalities plaguing most Metropolitan cities: congestion and pollution. However, policymakers, particularly in developing countries, tend to resort to non-price alternatives like road space rationing to solve these externalities. Using a structural model of mode choice, the welfare cost of the road space rationing policy is analyzed in comparison to two tax-based policies: a vehicle mile tax and a cordon charge. In the absence of a revenue redistribution system, for the same reduction in total car trips, the consumer surplus loss for commuters in all income groups is higher under a tax scheme compared to road space rationing. Revenue recycling reduces the surplus loss, but the mechanism may not exist in developing countries. Though the evidence of welfare effects is from Santiago, Chile, the findings offer evidence of the dilemma policymakers often face between choosing an economically efficient policy and one that suits the voters.



*Keywords:* Driving restriction; Road Pricing; Mode Choice; Welfare effects

## 1. Introduction

A basic economic principle is that consumers should pay for the costs they impose on others as an incentive to use resources efficiently. Applying this principle to the transportation sector, if road space is unpriced, more trips would be undertaken than required and traffic volumes will increase until congestion limits further growth. Similarly, if emissions are not taxed, vehicle owners would not have the incentive to invest in fuel efficient vehicles. For decades economists have recommended road pricing and emission taxes to encourage more efficient use of the transport

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system, addressing congestion as well as pollution problems. However, proponents of pricing instruments have been frustrated at the political resistance they face in most cities.

Policymakers usually consider multiple travel demand management policies to deal with these externalities. However, the challenge is to meet the policy goal while considering the distributional concern associated with it. The gravity of the problem is higher in developing countries where most of the population is still in the middle- and low-income segments. Politicians are usually concerned that a tax or toll to correct traffic externalities would hurt all commuters, particularly the poor who spend a higher fraction of their income on transportation. Considering how voters may react to a rise in their daily commuting cost, they often resort to non-tax alternatives like a road space rationing policy.

Analyzing the mode choice decision of commuters and their demand response to different policy scenarios involving a vehicle mile tax, a cordon charge, and driving restriction, this study examines the trade-off that policymakers face in their choice of mechanism to deal with traffic externalities.

Studies on welfare effects of price-based alternatives like congestion pricing have found that if a toll applies only to private auto trips, and there is an efficient redistribution mechanism to recirculate the revenue to improve the overall transportation network or lower labor taxes, the effect may be less averse for commuters (Parry and Bento, 2001; Small, 1992). Moreover, in a developing country, where low-income commuters tend to use the public transit system to commute to work, a congestion pricing scheme like cordon charges on auto drivers near the central business districts (CBD) may affect the wealthy more than low-income commuters (Linn et al., 2015). Despite all the favorable economic arguments and successful implementation of pricing schemes in Singapore, London, and Stockholm, there is still a lack of acceptance by general public (Grizolia et al., 2015). Lack of confidence in the revenue recycling mechanism, lack of information about the benefits, and general perception of taxes being regressive are some of the factors that affect acceptance of road pricing schemes (Ramos et al., 2017).

The choice of road space rationing to reduce vehicle emission and congestion is based on the idea that vehicle owners tend to belong to higher income groups. Therefore, the policy would affect only commuters from the wealthier segments and restrict their auto trip demand. In reality, the effect of the driving restriction can also be heterogeneous both across and within income segments, particularly for the middle-income group. While high-income households usually have multiple vehicles, those in the middle-income category may not always be able to invest in a second vehicle. Thus, the policy can have a differential effect on middle-income households depending on their ability to purchase multiple vehicles and access to other modes of transport (Gallego et.al., 2013(a)).

Past studies analyzing the driving restriction policy have primarily concentrated on the outcomes of the policy - pollution reduction, congestion, or cleaner vehicle fleet. In most of the cities where the policy is implemented, including Santiago, the main aim is reduction in vehicle emissions of criteria pollutants namely, carbon monoxide, nitrogen oxide, volatile organic compounds (VOCs), and particulate matter. In almost all the cases, the government at first introduced the policy with a short-term goal and was successful in achieving the target to a great extent. However, as the restrictions were made permanent, commuters in the medium and long run adapted to bypass the restriction by purchasing multiple vehicles or by changing the trip time. Davis (2008) observed that sometimes the second vehicle purchased to avoid the restriction was old and more polluting worsening air pollution. Policymakers have tried to contradict these behavioral changes of commuters by extending the restriction hours and exempting clean fuel vehicles while making the policy stricter for older cars. In the medium and long run, though there is evidence of fleet turnover towards cleaner vehicles (Barahona et al., 2015), the main objectives of the policy tend to get invalidated as more vehicles get exempted. Overall, except the study by Carillo et al. (2013) of the driving restriction policy in Quito, Ecuador[2], all the past analysis on the effect of driving restrictions on air pollution have concluded that the policy fails to reduce vehicle emissions in the medium and long run as people adapt to the restriction (Lin et al., 2011, Lawell et al., 2015, Guo and Li (2016) and Gallego et al., 2013(a, b)).

Using a traffic flow model, Cantillo and Ortuzar (2014) showed that the inability to use vehicles creates a social loss. In the long run, as consumers respond by either purchasing a second vehicle or by rescheduling their trips, the desired effect of the road space rationing policy is lost both with respect to pollution and congestion. Moreover, as the

[2] The authors found a positive impact of the driving restriction in terms of reduction in CO levels in Quito, Ecuador

authors mention, when households buy a second vehicle, they tend to use both on days when neither are restricted leading to an increase in car flows on weekends and hours during which the vehicular restrictions do not apply. de Grange and Troncoso (2011) studying the effect of the policy on vehicle flow in Santiago, Chile found that the policy reduces vehicle flow in the city only by 5.5% on days of environmental emergency when usually exempted vehicles are also restricted, far less than the intended 60%. Even in case of Beijing, China, Wang et al., (2013) failed to find any effect of the policy on auto demand and car flow.

Even though Governments choose policies like road space rationing based on welfare arguments, the literature has largely ignored the analysis of the incidence of the policy. Blackman et al. (2015) used a contingent valuation approach to calculate the costs of the driving restriction program in Mexico City. The paper focused on quantifying the incidence of the program by estimating the commuters' willingness to pay to get an exemption from the restriction. On average, a vehicle owner would be willing to pay roughly 1,000 pesos (approximately 121 USD) per year for a driving restriction exemption. Considering the fraction of their total income a commuter would have to spend to get an exemption, the authors concluded that the policy is regressive. Nie, Y. (2017) offered similar conclusions analyzing the welfare consequences of the driving restriction policy with a numerical model. However, a theoretical model developed by Zhua et al. (2013) indicate that welfare effects can differ between the short and long run when heterogeneity in travel behavior and traffic network congestion of a city is considered In the short-run, when a relatively small percentage of users are rationed off the roads and the induced demand due to congestion mitigation from the rationing policy is low (commuters have not adjusted to the new policy) road space rationing creates lower welfare loss than road pricing.

Instead of considering the outcome of the policy, the present study aims to analyze the welfare cost of the driving restriction policy based on commuters' travel mode choice decisions and compare it with that of alternative tax-based instruments, namely, a vehicle mile tax and a cordon toll. The analysis is based on data from the 2012 Travel Survey done in Santiago, Chile. Mode choice decisions of commuters are analyzed using a discrete choice model-logistic regression.

Estimates of consumer surplus loss reveal that driving restriction entails a compliance cost for commuters from all income groups but hurts middle-income commuters more than those from high- or low-income segments. The driving restriction policy scenario estimated here reflects the `regular' restriction conditions whereby a certain fraction of only non-catalytic converter vehicles is restricted. As observed in a previous study by (Gallego et al., 2013(a)), high-income households tend to have multiple cars and can invest in clean fuel vehicles while low-income commuters tend to not use the auto option on a regular basis. It is the middle-income household that often has a single vehicle and high utility associated with it. Hence, the policy can hurt this segment of commuters the most. In the current study, the result is driven by the loss in commuters' utility due to the necessity to shift to transit or taxis from their private vehicles. Taxis are expensive in Santiago, particularly for longer trips. As a result, commuters from middle-income households may not find them affordable and are forced to choose the slower transit option. The welfare effect that is measured here is the first-order effect of the driving restriction policy on ‘general travel costs’ of a commuter with limited transportation choices. The ‘travel costs’ would include the opportunity costs of time spent on travel by other modes, the direct pecuniary and non-pecuniary costs of travel. Comparing the incidence of the driving restriction policy with that of alternative tax-based policies it is found that, for an equal reduction in total auto trips, the consumer surplus loss is higher for all the income groups. This is also a first-order effect of the pricing policies without taking into account the effect of reduced travel time on the utility of commuters and the presence of a revenue recycling mechanism. However, when the latter is taken into consideration whereby each commuter receives a lump sum transfer of the same amount, the consumer surplus loss is lower under road pricing than under the driving restriction policy. Unfortunately, if cities lack an efficient mechanism to recycle the toll revenue, the first-order effects are more probable.

This study is not only relevant to the transportation policy scenario in Santiago, Chile, but also in other major cities of developing countries. In all the metropolitans where a city government considers the road space rationing policy, pricing instruments are also considered. Until this date, the latter set of alternatives have failed the distributional-concern test, so that policymakers resorted to other travel demand management policies. However, ongoing pollution concerns have compelled the governments in these cities to reconsider congestion pricing as a way to reduce driving in the affected regions. In this situation, it is important to have a comparative analysis of the welfare costs of these different policies under the constraints that are usually present in a developing country.

## 2. Characteristics of the License Plate Based Driving Restriction in Santiago, Chile

A driving restriction based on license plate number has been in place in Santiago Province, Chile since 1986. The city suffers from severe pollution problems due to its geographical setting during autumn and winter months when a thermal inversion sets in. The restrictions are traditionally in force from April through August every year for all four (or more) wheeled private motorized vehicles that do not have a green sticker, i.e. not equipped with catalytic converters (also called non-green seal [NGS]). According to the policy, if the license plate number ends with a particular digit and it is an NGS vehicle, then it cannot be driven on certain days of the week. Originally, the restriction was on 20% of the NGS cars, but in 2008 it was increased to 40% of the NGS fleet. The policy is effective on weekdays between 7:30 a.m. and 9 p.m. Weekends and holidays are exempt. (Note: from April 2015, the restriction has been made permanent for NGS vehicles. NGS vehicles are not allowed to enter the city limits between 7:30 a.m. and 9 p.m.)

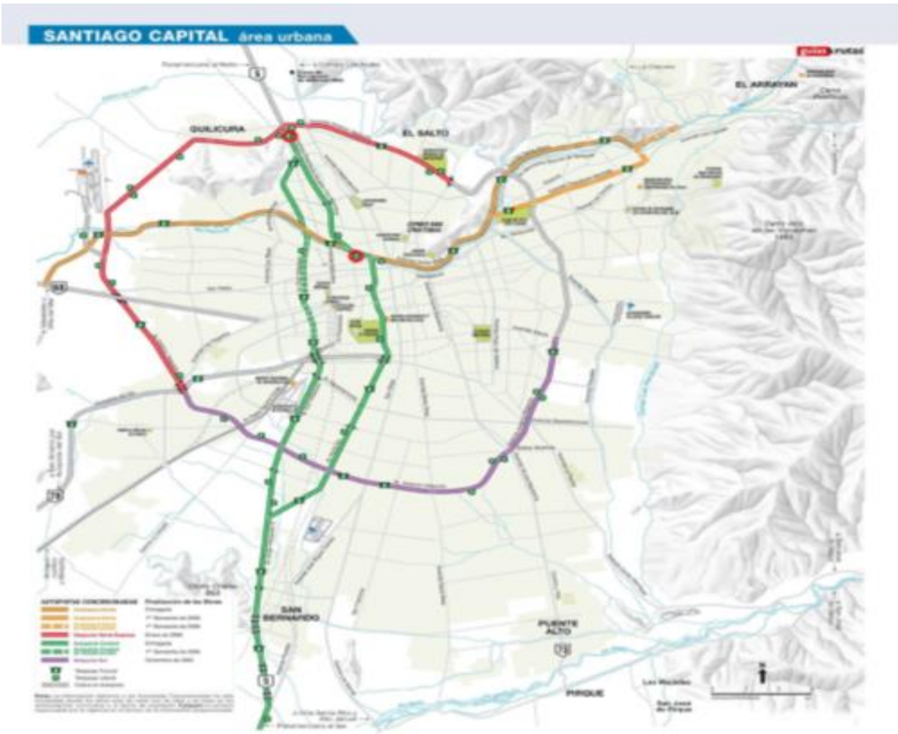


Fig 1: Santiago Metropolitan Region

From the beginning, the restriction applied to NGS vehicles only. One of the objectives was to encourage general upgradation to lower emission vehicles. To incentivize the turnover, a new decree was promulgated in 1991 which required any 1993-and-later models registered in Santiago and surrounding areas to be equipped with a catalytic converter (otherwise they could not be registered in Santiago). These vehicles (also called green-seal [GS]) were exempted from the restriction. This encouraged households to buy cleaner vehicles. In their study on vehicle ownership and fleet turnover in Santiago, Barahona et al (2015) find that households preferred 1993 cars over 1992 ones. This preference is primarily attributed to the nature of the driving restriction policy. From 2018, even GS vehicles registered before September 2011 has been subjected to the restriction during the winter months. As before, we can expect this change in policy to incentivize households to purchase newer fuel-efficient vehicles and alternative fuel vehicles.

However, further research is required to understand the effect of this policy on vehicle ownership, miles travelled, use of shared mode of travel, and congestion in public transport.

Increased car ownership over time and more exemptions imply that stricter restrictions are required to deal with periods when air pollution goes beyond acceptable limits, described as ‘critical episodes’. Depending on their severity, these episodes are classified as an alert, a pre-emergency, and an emergency. The ‘critical episodes’ are classified based on PM10 levels (ICAP scale). E.g. an emergency alert is declared when PM10 levels cross 200 ICAP[3]. On these days, a certain percentage of GS vehicles are also restricted along with an increased number of NGS vehicles. Since 2001, the additional restriction on pre-emergencies covered 20% of GS vehicles whereas the emergency restriction extended it to 40%.

In spite of the restriction on 40% of vehicles, de Grange and Troncoso (2011) in their study of the impact of vehicle restriction on urban transport flows found that the reduction in car trips on regular restriction days is negligible. A plausible reason for this result is that only 4% of the vehicle fleet of Santiago was NGS in 2012. Hence, 40% of 4% implies that a mere 1.6% of the vehicle fleet is affected by the policy on a regular day. However, vehicle flow reduction varies between 5-7% on pre-emergency and emergency days when GS vehicles are also restricted. Even though the drop is larger, this reduction is lower than the target of 20-40%. There are multiple reasons why this might be the case: multi-vehicle households, a shift of travel demand outside the restriction period, or poor enforcement.

Overall, even when enforcement is not perfect, the design of the driving restriction policy usually incentivizes ownership of cleaner vehicles while the old and more polluting ones are kept off the road. However, as the motorization rate rises in the city, it necessitates other travel demand management strategies. The Government of Santiago invested in a centralized public transit system in 2007 and toll roads (private-public partnership) to deal with its rising traffic and its related externalities. Santiago, along with other Latin American cities like Buenos Aires and São Paulo are also actively considering policies like cordon charges, time-varying road pricing in high congestion areas, and a cap-and-trade system of emission rights for mobile sources.[4]

Using Santiago, Chile as a case study, a structural model of travel mode choice is estimated to analyze the welfare cost of the driving restriction policy when mode availability is limited by the latter. Subsequently, the welfare cost is compared to that imposed by a vehicle mile tax and a cordon charge for an equal reduction in total car trips. The presence of the transit infrastructure and toll roads enabled access to reliable data on public transportation and a baseline estimate of commuters' willingness to pay for time saving (toll rates).

## 3. Survey Details and Mode Choice Data

### *3.1. Survey Details*

The data used for the mode choice analysis comes from the Santiago Origin-Destination Survey-2012 done by the University Alberto Hurtado for the Executive Secretary of the Planning Commission Investment in Transport Infrastructure (SECTRA, 2012). The objectives of the study were to (i) collect information required to characterize the patterns of urban travel and socioeconomic characteristics of travelers, (ii) conduct measurement of the flow and occupancy rate of the external cordon of the Santiago Metropolitan Region, (iii) measure the use and level of service of the public transportation system and the use of private vehicles, (iv) build databases and geographic information systems (GIS) using the information collected, and, (v) gather data on non-motorized travel.

The survey was conducted in 45 communes of the Santiago Metropolitan region, where a commune is the smallest administrative unit in the region. It is equivalent to a municipality. It may contain cities, towns, as well as rural areas. Each commune was subdivided into multiple zones (a total of 876 zones in 45 communes). The zoning method of

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[3] The Illness Costs of Air Pollution (ICAP) is an index to measure air quality and the associated health effects.

[4] “Could congestion charges work in Latin America” (Citylab, May 29, 2018)

previous travel surveys was re-evaluated with the objective of including new areas of urban development into the study sample, namely, target areas for investment in the transportation system and other real estate developments.

The sample design for the survey used the method of probability proportional to size (PPS) with replacement[5] to select the clusters in a zone to be surveyed, where the size of each cluster was determined by the number of households in that block. Then, within each cluster, 'n' households were randomly selected. A surveyor contacted households in person with a cover letter. If the household consented then the surveyor gave them a questionnaire requesting demographic and vehicle holding information like age of respondent, income range, education, kind of vehicles in the household, vintage, and fuel type. For the questionnaire related to trip information, each household was randomly assigned a day of the week to record the information of every trip taken on that particular day. In the case of continued participation, the surveyor made a second visit to the household and collected the information in person. Each household and respondent in the sample were assigned raked weights based on the number of urban dwellings in that commune as recorded by the pre-census 2011 data, household size, and vehicle ownership.

The final survey dataset included 18,264 households. On the assigned day of the travel log, each household member had to enter the details of every trip they made on that day, including multiple stages in a particular trip. In total, there was mode choice data for 113,591 trips. The survey considered even children or very old people as possible commuters.

The survey was conducted between July 2012 and November 2013. Hence, the survey period includes both the phase when the road space rationing policy or the driving restriction is enforced in Santiago (July 2012-August 2012 and April 2013-August 2013) as well as the time period when there is no restriction (September-March). Descriptive statistics of the survey sample is given in Table 1. According to the income brackets defined in the survey document: \$0-\$1,152, \$1,153-\$4,608, and, \$4609, there are 1,165 high-income households, 10,098 middle-, and, 6,983 low-income households in the sample respectively. All income levels are expressed in US dollars. In terms of vehicle holding, 11,067 households (60%) do not own any vehicle. 5,780 are single vehicle households (32%) and 1,399 (8%) have two or more vehicles.

Table 1: Descriptive Statistics of Survey Attributes- Sample and Population

| Attributes | Metropolitan Region<br>Person: 6,849,310 | Survey Sample<br>Person:60,054 | Weighted Sample<br>Person: 6,651,700 |
|---|---|---|---|
| Avg. household income (monthly) | USD 2,548.2 | USD 2,027.1 | USD 2,035.7 |
| Avg. income per capita | USD 857 | USD 703.3 | USD 701.2 |
| Household size | | 3.34 | 3.2 |
| Number of vehicles (non-trailers) | 1,597,762 | 8,887 | 1,157,391 |
| Number of green-seal vehicles (with catalytic converters) | 1,533,885 (96%) | 6,593 (74.2%) | 866,137 (74.8%) |
| Median Age: | 34 years | 37 years | 33 years |
| 0-14 years | 1,459,756 (20.7%) | 7,618 (16%) | - |
| 15-59 years | 4,653,364 (65.9%) | 31,071 (67%) | - |
| 60 years & above | 944,371 (13.4%) | 7,551 (16%) | - |
| Gender (male) | 49% | 47% | 49% |

[1]Household income measured in Chilean peso is converted to US dollar using a PPP factor of 347.2 (OECD, 2013)

[2]The weighted sample measures are based on the raked weights of the household used in the survey

### *3.2 Sample Formation*

[5] Probability proportion to size is a sampling procedure under which the probability of a unit being selected is proportional to the size of the ultimate unit, giving larger clusters a greater probability of selection and smaller clusters a lower probability.

The travel survey recorded the mode choice decision of each member of the surveyed household for all the trips taken on the assigned day. The respondents reported mode specific attributes like the fare paid in the case of public transit, taxi, or jitney, parking cost for their car, travel time, wait time, and time to access the mode of transport among others. In addition, the survey also obtained data on demographics both at the household and individual level as well as details on the vehicle holdings.

According to the survey questionnaire, individuals could choose to drive a car or be a passenger, use the TranSantiago system (bus, metro, or, both), a non-TranSantiago bus (rural-urban or feeder bus), taxi, jitney, motorcycle, train, bicycle, walk, or any combination of these modes. Since children are also included in the survey, one of the reported mode choices was school bus. In order to analyze the data in the mode choice framework, the options are first consolidated into four categories: auto (as driver or passenger), public transit (TranSantiago, non-Transantiago bus, and jitney), taxi, and non-motor mode (walk/bicycle). Since multiple modes could have been used in a single trip, in the absence of information on distance traveled by each mode, the categorization is done based on the mode used in the 'last mile'. Trips for which school bus (as passenger or driver), motorcycle, informal service, or the train were reported as the chosen mode are dropped from the sample used for analysis. (Note: There is only one train route that is primarily used for commuting to the Metropolitan region and there were only 4 trips in the sample for which it was a chosen mode. Even if motorcycle is a common mode of travel in a developing country, any pricing or quantity restriction policy tends to exempt this mode of travel. Also, school buses are exempted from restrictions as they serve a particular group of commuters only.)

Secondly, to model the mode choice decision of individuals, data is required on the mode-specific attributes of not only the chosen alternative but also for the other options available to an individual. In particular, data on cost and travel time is needed. External resources like the Google Distance Matrix API service, the Transantiago website, Comision Nacional de Seguridad de Transito (accident data), Ministry of Public Works website (toll rates), OECD reports, and previous studies on the transportation sector in Santiago have been used to impute the data for the non-chosen modes. The following table gives the list of variables and the sources used for the data imputation process.

Table 2: Data Imputation for Mode Alternatives

| Attribute | Mode of travel | Data imputed & Use | Source |
|---|---|---|---|
| Cost of Travel | Auto | Distance for cost per mile | Google distance matrix, OECD Report |
| | Auto | Per mile toll for cost per mile | Toll road websites |
| | Auto | Average Parking cost per location | Survey data |
| | Transit | Fare per trip | TranSantiago website, Metro De Santiago, Survey data |
| | Taxi | Fare per mile | www.numbeo.com |
| | Walk/Bicycle | Cost of non-motor mode travel | National Committee for Traffic Safety (CONASET) |
| Travel Time | Motor modes & Walk | Trip time for best route (peak time adjusted) | Google Distance Matrix |
| | Bicycle | Trip time for best route (no toll or freeway route) | Google Distance Matrix |

*3.2.1 Data Imputation for Mode Alternatives*

Travel cost and time for the non-chosen modes were imputed using the following method:

- **Trip Cost by Auto**: Google Distance Matrix service was used to obtain the distance traveled in miles for each origin-destination pair reported in the survey data. Only trips for which both the origin and destination coordinates were reported are considered. For trips with multiple stages, the distance between the final destination point and the origin is obtained from Google. Assuming an average fuel efficiency of 33 miles per gallon and a fuel price of \$3 for gasoline, \$2 for diesel, and \$4 for compressed natural gas, the per mile cost of travel by auto is calculated.[6] Vehicle ownership in Santiago involves an annual technical review and insurance cost. These fixed costs (per day) are added to the cost of travel by auto.

For the observed mode choice decisions, if the trip by auto involved a toll road, then the toll cost is added to the total trip cost. Respondents reported the name of the tolled road that they used during a trip. If the entire trip was completed using the tolled road, the toll cost was calculated as the per mile toll charged according to the time when the trip was taken times the distance between the origin and destination point (by auto mode). Trips for which multiple tolled roads were used was dropped from the data used for analysis because there was no information on the points of entry and exit for the different tolled roads. When 'auto' is not the chosen mode, the toll costs were imputed using the predicted values of a linear regression model of toll amount on availability of toll road for an origin-destination pair, departure time, purpose of the trip, nature of the trip (long or short distance), and demographics like income and gender. In the regression analysis, toll road is considered available for an O-D pair if the origin and destination are within 3 miles of an entrance and exit to a toll road.

If parking costs are reported, then they are added to the trip cost by car. When 'auto' is not the chosen mode, then the average parking cost differentiated by destination of the trip has been added to the cost of travel.

Therefore, when auto is not the chosen mode, the trip cost by auto is calculated as:

$$\textit{Cost of Travel by Auto} = \textit{Gallons per mile} * \textit{Cost per gallon} * \textit{Distance} + \textit{Fixed Cost} + \textit{Average parking cost} + \textit{Toll road cost (if available for O-D pair)} \quad (1)$$

When auto is the chosen mode, then trip cost includes the reported toll value and parking charges.

- **Trip Cost by Public Transit**: The observed mode choice could include the TransSantiago bus system, Metro, rural-urban buses, the intra-city feeder buses, and jitney as public transit. The cost of travel is reported for only the non-TranSantiago options. Hence, the cost of travel by public transit when it is not the chosen mode as well as for the observed choices using the TranSantiago system is imputed using the fare information available on the TranSantiago website. The fares vary by the time of the day and the combination of bus and metro system used. During the peak period, the cost of a trip using the bus-metro combination is 740 Chilean pesos or US $1.11. The mid-peak rate is 660 pesos (US $0.99) and the off-peak cost is 640 Chilean pesos (US $0.96). The elderly (age 60 and above for women and age 65 and above for men) and students (middle school up to college degree studies) get a pass worth 210 Chilean pesos (US $0.315). These discounts are considered in the imputation process using the survey data on age and current educational status of each respondent.

- **Trip Cost by Shared Mode (Taxi and Jitney):** The cost of travel by taxi when it is not the chosen mode is calculated using information on per mile taxi rate in the Santiago region and the distance reported by Google Distance Matrix for the origin-destination pair (auto mode).

- **Trip Cost by Non-Motor Mode (Walk and Bicycle)**: There are no fuel cost, fare, or, parking cost reported for the non-motor modes. However, the risk associated with the usage of these modes can be monetized. Bicycle and walking are commonly used modes of travel in developing countries due to their lower operation cost compared to other motor modes. However, the risk of fatal accident associated with the mode when it must share road space with auto and the transit system is high. 34% of the fatal accidents in Chile in 2015 involved pedestrians and 8% involved bicyclists. The exposure risk for pedestrians and bicyclists is calculated as the fraction of accidents in each category in 2012 to the total number of vehicle miles traveled (motor and non-motor). The total number of trips taken in the Santiago Metropolitan region on a particular day in 2012 was 18,461,100 (EOD 2012). Assuming the average trip length is 8 miles, the total number of

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[6] Source: www.globalpetrolprices.com and Lopez-Global-Fuel-Economy-Initiative-Chile-Case-Study for average fuel efficiency of vehicles in Chile

vehicle miles was 147,688,800 miles. This implies that the risk of accident for pedestrians is 5.546 X $10^{-5}$ and that for bicyclists it is 2.223 X $10^{-5}$. Considering the total cost of accidents was 404 million USD in 2013 (Road Safety Annual Report, 2015)[7], the cost of road crash per mile is 2.735 USD. Hence, the expected cost for pedestrians (per mile) is 0.00018 USD and for bicyclists it is 0.00012 USD.

Since walking and the bicycle mode have been combined under one category, a distance rule is used to impute the cost of travel by the non-motor mode for each O-D pair (Zegras 1997). Based on the observed choice of mode, the distance rule was developed using a simple linear probability model of choice of non-motor mode as a function of distance of the trip. Walking is the chosen mode if the distance of the trip is less than 10 miles. The probability of choice of `walking' as a mode falls beyond 10 miles and hence, for trip distances between 10 and 40 miles `bicycle' is considered as the non-motor alternative. For trip distances beyond 40 miles non-motor mode is not available as an alternative (Bhatt 2000).

Travel time obtained from Google Distance Matrix for each origin destination pair is used for all the trips. In order to avoid reporting error in the data, the responses of the surveyed individuals are not used for the purpose of analysis. The travel time obtained from Google service is conditional on the traffic conditions at the time of query. In the case of peak period trips, the query was adjusted to account for potentially longer travel times.

- **Travel time by Auto**: Travel time for the auto option is extracted directly from Google Distance Matrix accounting for potential longer travel time during the peak periods of the day.

- **Travel time by Public Transit:** The travel time for the transit option is the sum of the time obtained from Google Distance Matrix service for the transit option and the average wait time estimated from the sample. As in the case of trips by auto mode, except for trips made during peak period, the travel time obtained from Google service is conditional on the traffic conditions at the time of query. In the case of peak period trips, the query was adjusted to account for potentially longer travel times.

- **Travel time by Shared Mode (Taxi and Jitney)**: For the shared mode, the travel time by auto as obtained from Google Distance Matrix query for the origin-destination pair is used. Average wait time estimated from the survey data is added to the travel time when taxi or jitney is not the chosen mode.

- **Travel time by Non-Motor Mode (Walk and Bicycle):** Travel time when the chosen mode is `walking' is obtained from Google Distance Matrix. However, in the case of Santiago, Google maps does not report time for the bicycle option. Hence, travel time is calculated as distance by car with no freeway or tolled road usage (as obtained from Google) multiplied with an average biking speed of 15 km/hour (9.3 miles/hour).

As a result of the data imputation, the final dataset has information on travel time and cost for all possible modes of travel for each member of the household (head of the household, spouse, kids, other relatives, domestic help). All the cost measures in the data and those derived in the subsequent sections have been converted from Chilean pesos to US dollars using the OECD Purchasing Power Parity (PPP) conversion factor. The PPP conversion factor measured in terms of national currency per US dollar was 347.2 in 2012.

Only complete trips (multiple stages of the trip were collapsed) for which coordinates of both origin and destination were reported have been retained for analysis. This method of sample retention was required to get information on time and distance about the other modes from Google Maps. Additionally, only trips that were completed in the Santiago Metropolitan region were considered for analysis. As most daily trips are undertaken in the Santiago Metropolitan Region, any transportation policy would primarily impact trips in this area.

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[7] The cost of a road crash in Chile is calculated according to the Human Capital Approach.

## 4. Empirical Analysis: Mode Choice Model

The model of mode choice includes four sets of variables: mode-specific attributes, trip characteristics, household socio-demographics, and mode-specific constants. Mode-specific attributes include monetary cost of travel, travel time, wait time, and time to access the mode. Trip-specific attributes include the destination of the trip, purpose of the trip, day of the week, and the income category of the commuter. The income categories were developed according to the OECD definition of `middle', `affluent', and, `disadvantaged' income groups for developing countries. The lower and upper bounds of per capita income for the middle-income group are defined as 50% and 150% of median per capita income in the year of study. This method makes the group comparable across countries.

The mode choices available to a commuter depend on the vehicle holdings of their household, eligibility to drive, and availability of transit options given the origin and destination of the trip. However, when there are more commuters than vehicles in the household, the decisions of the members are interdependent in terms of availability of auto as an alternative in the choice set. Modeling the choice of every member of the household would require joint estimation of their mode choice decisions. The ordinary logit model is not appropriate in this scenario. Moreover, if the household has two vehicles and there are multiple licensed drivers, it is not possible to allocate the vehicle to any one member without further information on vehicle use. Also, it is difficult to allocate mode alternatives under the driving restriction, particularly if the household has a combination of GS and NGS vehicles. A potential way of dealing with the vehicle allocation problem and availability of alternatives in the decision set of commuters is a random allocation of vehicles among the members in the household who are eligible to drive. Though this might give an idea about the effect of mode specific attributes on the choice decisions, the estimates of the market share of each mode or the distributional effect of altering any attribute of a mode may not be reliable.

Avoiding the interdependency in the mode choice decisions of a household and potential misallocation of alternatives, only the decision of the head of the household of zero and single-vehicle households has been modeled here, assuming that the head of the household gets the auto option when available. Moreover, as the mode choice of the first trip of the day would usually determine the choice of mode for subsequent trips (mostly they are round trips), only the first trip of the head of the household is considered. There is no doubt that this estimation strategy results in underutilization of information about the choice decisions of other members of the household. Also, it is fair to argue that the license-plate based driving restriction or any other policy would affect all members of a household. In spite of these limitations, this model should still be able to capture the effects of mode and trip specific attributes on the choice decision as well as give a lower bound estimate of the change in consumer surplus under different policy scenarios.

Even though the survey covered the time of the year when the license-plate-based restriction is enforced in the Santiago Metropolitan region, there is no information on whether a particular household vehicle was restricted on the assigned day of travel. Therefore, it was not possible to analyze the mode choice of the sample of households with vehicles surveyed during the restriction period. However, as households were randomly selected in both periods, it can be assumed that the preferences of the households surveyed in either period with respect to mode-specific attributes like trip cost, time of travel, accessibility, or convenience would be similar. Hence, the sample of households are split into two on the basis of the day/period of the survey and the final sample has zero-vehicle households from both the periods and one-vehicle households surveyed in the non-restricted period. In the absence of data on restricted vehicles for a particular household, this was done to avoid any misallocation of mode alternatives.

### *4.1. Estimation Results*

The results of the conditional logit model of mode choice are presented in Table 3. The coefficients gives the effect of mode specific attributes, namely, trip cost, travel time, and access time on mode choice decisions controlling for purpose of the trip, destination of the trip (central business district or not), day of the week, and income category of the household member. For the transit and shared mode category, time of travel includes the in-vehicle travel time and wait time. Non-motorized mode is considered as the reference category in the logit model.

Trip cost is multiplied by the household's income category to reflect differential cost sensitivity of households. While trip cost has a negative impact on choice for all income categories, head of low-income households are more cost sensitive than those in the middle- and high-income groups. Accessibility to a mode is measured in terms of the time it takes to access the mode of travel. As expected it negatively affects the choice of a mode.

Though jobs have spread throughout the Santiago Metropolitan region over the past decade, the commune of Santiago is still one of the main business districts in the region. For trips with the central business district as the destination point, it is observed that public transit and taxi is preferred to a non-motor mode of travel but auto is not. This may be due to high parking costs in the business district or due to congested roads during peak hours. Also, Santiago is well-connected to the surrounding regions by the transit system via metro. These factors might dis-incentivize people from taking their car to the central business district (CBD). The same reason can explain the negative relation between work as purpose of the trip and choice of auto mode. It is observed that, on average, individuals are less likely to travel by auto to work compared to non-motor modes. Considering the mode preference of different income categories, it is observed that a commuter from a high- and middle-income household has a higher preference for the auto option than other modes compared to the head of household from the low-income category.

Table 3: Conditional Logit Model - Head of the Household Mode Choice Decision

| Variable | Coefficient | (Std. Err.) |
|---|---|---|
| Trip Cost X High Income | -0.130** | (0.012) |
| Trip Cost X Middle Income | -0.143** | (0.009) |
| Trip Cost X Low Income | -0.206** | (0.024) |
| Travel Time | -3.548** | (0.092) |
| Time to Access Mode | -1.490** | (0.257) |
| Destination CBD X Transit | 0.172* | (0.082) |
| Destination CBD X Shared Mode | 0.567** | (0.179) |
| Destination CBD X Car | -0.721** | (0.124) |
| Purpose of Trip: Work X Car | -0.978** | (0.093) |
| Middle Income X Car | 0.804** | (0.186) |
| High Income X Car | 1.145** | (0.190) |
| Weekday X Car | 0.107 | (0.110) |
| Weekday X Transit | 0.728** | (0.070) |
| Car/Auto | -1.782** | (0.226) |
| Transit | 0.768** | (0.090) |
| Shared Mode (Taxi) | -2.656** | (0.122) |

[1] Trip cost measured in Chilean Peso is converted to US dollar using a PPP factor of 347.2 (OECD, 2013)
[2] Travel time is in hours
[3] Destination CBD imply trips to the commune of Santiago.
[4] Low Income (0-USD 460), Middle Income (USD 461-USD 1380), High Income (>USD 1381). Incomes are monthly income.
[5] 1%:**, 5%:*, 10%†
[6] Joint significance tests of the interaction term of income with mode and income with cost was done. The null hypothesis could not be accepted at 1% level of significance

The estimated coefficients on the cost and time components give information about the value of time; the extra cost that a person would be willing to incur to save travel time. The value of time saving for different income categories is given in Table 4. For the high-income group the average value of time saving ($/hour) is estimated to be $27.3 USD, $24.8 USD for the middle- income, and $17.2 USD for the low-income group.

Table 4: Value of Time Savings

| | Value of Time Saving in $/hr | | |
|---|---|---|---|
| | High Income | Middle Income | Low Income |
| Value of Time (95% CI) | 27.3 (22.9,33.36) | 24.8 (22.24,27.75) | 17.2 (14.09, 21.98) |

Considering that in Chile the average household net-adjusted disposable income per capita is lower than the OECD average of $29,016 USD a year (for other developed countries), the value of time estimates are higher than expected.

This finding can be caused by two factors. Firstly, the survey was done in the Santiago Metropolitan region, which has a higher concentration of high- and middle-income households than the rest of the nation. As observed in Table 1, the average monthly household income in the Santiago Metropolitan region is high and comparable to that observed in developed nations, and hence, the estimated value of time is in the range observed in these countries. The average value of time for surface transport as estimated by the US Department of Transportation in 2013 was $24.5 (35%-60% of total earnings). Moreover, the model estimates the mode choice decisions for the first trip of the day. The first trip is usually undertaken to go to work or business and hence, the value of time savings may be higher. Also, the simple logit model may not be able to capture the high variation in the value of time in a particular income category, and a discrete choice model that allows a flexible distribution on income may give more reasonable estimates of the value of time savings.

## 5. Policy Scenarios and Implications

Policymakers usually consider a range of policy options to deal with an externality. However, tax-based policies that are popular among economists often fail to satisfy their welfare concerns, and as a result, other policy alternatives tend to be implemented. The license-plate-based driving restriction is one of those alternatives implemented primarily based on the welfare argument. The scenario analysis in this section aims to explore this welfare argument and verify whether or not the choice of policy based on it is justified.

Multiple studies have shown that the driving restriction policy does impose compliance costs on commuters. The latter may have to change their mode choice as their choice set becomes limited. As discussed by Blackman et al. (2015), driving restrictions prevent a household from using their car on some days of the week. This limitation can force a household to reduce or reschedule driving, increase travel by other modes with different travel times, sell its car, or buy another car. These adaptations are related to `generalized travel costs', which consist of the opportunity cost of travel time, the direct monetary costs of travel, and non-monetary costs like inconvenience. The welfare impacts estimated here capture only these first-order effects of the policy due to restricted travel options. It does not account for possible consumer surplus gains from reduced travel times when congestion falls due to the restriction policy. Likewise, it also does not include any welfare benefits from reduced pollution. The results of the scenario analysis should be interpreted accordingly.

In the scenarios with tax instruments, theoretically an appropriate combination of congestion charges and revenue recycling in improving transportation networks should be optimal (2). In other words, there should be a welfare loss (relative to the first-best) from any other policy. Though the current set-up does not account for any indirect effect of the tax scheme in terms of time-saving on transportation choice, revenue recycling in the form of lump sum transfer is incorporated in the model.

The welfare effect or compliance cost of a policy is measured in terms of change in consumer surplus from the base case scenario of ‘no-policy’ i.e., when there is no driving restriction or tax on driving behavior. The log-sum difference of expected utility (Small and Rosen 1981) gives the change in consumer surplus.

$$E(CS_i) = \frac{1}{\alpha}\left(\ln \sum_q e^{V_{iq}^1} - \ln \sum_q e^{V_{iq}^0}\right) \qquad (2)$$

where i=individual, q=alternatives, and α=marginal utility of money (assumed to be constant)

The results of the scenario analysis are given in Table 5. The first policy scenario considered in the study is the driving restriction policy practiced in the Santiago Metropolitan region until recently, whereby 40% of the non-catalytic converter vehicles were restricted on a particular day. In the sample of zero- and single-vehicle households considered here, 10% of the households had a non-catalytic converter car implying only 4% of the single vehicle households in the sample are affected. As a result of removing the auto option from these households, the reduction in consumer surplus observed under Scenario 1 in Table 5 (column I) is lowest for the low-income group and highest for the middle-income. Given the high cost of daily operation, the number of low-income commuters regularly choosing auto as the mode of travel is usually small in a developing country and hence, the policy does not affect their utility to a large extent. However, as middle-income households mostly have a single vehicle and taxi is an expensive mode, driving restriction may force them to use the transit system leading to a higher loss in consumer surplus. The high-income households, on the other hand, can potentially afford to travel by taxi with convenience and travel time similar to a car. This is a possible explanation for lower consumer loss on an average for this group compared to the middle income under the driving restriction policy.

The two pricing instruments that are considered here for the comparison of distributional effects are a vehicle mile tax and a cordon charge in peak traffic areas of the region. The Santiago Metropolitan region has both toll and non-toll roads. The vehicle mile tax scheme analyzed here would differentiate between trips undertaken using toll roads and those completed using surface streets. A commuter pays a vehicle mile tax only if they use the surface street. In this case, it is assumed that trips are completed using either surface streets or toll roads. In reality, however, commuters may use a combination of the two road types. The scenario with a cordon charge requires commuters to pay a fixed price to enter and drive in the communes of Santiago, Las Condes, and Providencia. Though Santiago is the main business district, in the past two decades job locations have spread to the other two communes. Hence, a large number of work trips require travel to one of these three regions. As a result, traffic jams and congested roads are severe problems in these areas. Also, the wealthier neighborhoods with high vehicle ownership are concentrated in these regions.

A grid-search algorithm is used to estimate the vehicle mile tax and cordon charge that would induce an equal reduction in total auto trips as the driving restriction policy. The vehicle mile tax required to attain the same reduction in auto trips as attained with the driving restriction policy on a `regular' day is estimated to be 20.5 cents per km. (Note: In 2015, during peak traffic hours the surface street speed in the Santiago region tends to fall to 12-18 km/hour. During similar hours, as the speed on toll roads fall below 50 km/hour, toll rate of 52 cents per km apply.) The cordon charge that would enable similar reduction in total auto trips is estimated to be $1.90. Past studies in the Santiago region have considered similar cordon toll values of $1.41, $2.83, and $5.66 to drive in specific regions and streets in the Metropolitan region (18). The study shows that a toll value less than 500 pesos or $1.41 may not be enough to cause any change in driving behavior. The distributional impact of the pricing policies is given under scenarios 2 and 3 in Table 4 (column II (a) and III (a) respectively).

Table 5: Policy Scenarios: Distributional Impacts

| Change in Consumer Surplus | Scenario 1 Driving Restriction Column I | Scenario 2 Vehicle Mile Tax Column II | | Scenario 3 Cordon Charge Column III | |
|---|---|---|---|---|---|
| | | No Revenue Recycle II (a) | Revenue Recycle II (b) | No Revenue Recycle III (a) | Revenue Recycle III (b) |
| High Income | -0.15 | -0.52 | -0.17 | -0.33 | -0.19 |
| Middle Income | -0.16 | -0.25 | 0.08 | -0.11 | 0.01 |
| Low Income | -0.01 | -0.05 | 0.27 | -0.03 | 0.09 |

[1] The change in consumer surplus is in dollar terms

[2] The consumer surplus is calculated using the logsum measure by Small,K and Rosen.

[3] No Government intervention is the base case scenario. Consumer surplus changes are estimated with respect to the base case scenario.

The change in consumer surplus estimated under scenarios 2 and 3 indicates that, in the absence of revenue recycling, a vehicle mile tax hurts all the income groups more than the driving restriction, particularly the high- and middle-income households. This is expected considering that vehicle ownership and choice of auto as a mode of travel on a regular basis is more prevalent in these income categories. As households in the low-income strata tend to use the public transit and non-motor mode of travel, the loss in consumer surplus is less in comparison to the other groups, but higher compared to the driving restriction policy scenario. The change in consumer surplus measures given in columns II (a) and III (a) of Table 5 are an estimate of the first-order effect of a tax policy.

When revenue recycling is considered, then the surplus loss under the tax schemes is lower than those under driving restriction for all income groups. If the revenue collected from the vehicle mile tax scheme is redistributed as lump sum transfer with each commuter getting $ 0.32 as a compensation for the loss in utility, there is consumer surplus gain for the middle- and low-income commuters (column II (b)). Similar results are observed for the cordon charge scheme. The areas where the cordon charges are imposed are primarily the wealthier neighborhoods with high vehicle ownership and propensity to drive. Linn, J et al. (2016) reported analogous results in their study on congestion pricing in Beijing, China. A cordon toll imposed around the CBD of Beijing would affect the higher-income commuters more than other income groups. As indicated in Table 5, if the revenue from the cordon toll is redistributed as a lump sum transfer of the amount of $ 0.13, the consumer surplus loss is lower for all income groups compared to the scenario with driving restrictions.

Overall, the results of the scenario analysis reflect the dilemma policymakers' face. Pricing instruments are economically efficient and may encourage more efficient use of resources. However, the welfare effect of the tax schemes is negative for commuters from all income groups. Though a redistribution mechanism that allows efficient recycling of the toll revenue reduces the consumer surplus loss from the tax schemes, in its absence, the driving restriction policy imposes lower welfare concern. A comparison of compliance cost in term of consumer surplus loss lends support to the choice of policy.

## 6. Conclusion

This paper examines the incidence of the driving restriction policy and compares it with that of tax-based instruments, namely, a vehicle mile tax and a cordon toll using scenario analysis. In the absence of a revenue recycling mechanism, the policymakers' choice of the driving restriction alternative to deal with traffic externalities does impose a lower burden on commuters compared to tax schemes. Considering the first-order effects, it might be both politically more feasible than a tax system and better in terms of welfare impact. On the other hand, if there exists a revenue recycling mechanism, it can reduce the compliance cost and generate better welfare impact than a non-tax alternative.

In a developing country, it might be difficult to convince voters of the existence of a well-functioning revenue recycle system whereby the tax revenue will be invested in improving the transportation system or used to compensate commuters through other channels. There is a fair chance that the revenue gets redirected to other sectors (that does not affect the commuter directly) or it is lost in corruption. Revenue can also be recycled through reduction in labor taxes compensating for the higher commuting cost due to road pricing. However, in a developing country where the majority of the population are in the informal sector, reduction in labor tax may not be feasible or effective.

The driving restriction program is practiced in other Latin American cities such as Sau Paulo, Bogota, and Quito, as well as in Beijing. Although the particular experiences of the different policy scenarios would differ across these cities based on their existing transportation infrastructure, mode choice patterns, and income distribution, the above estimates give an idea of why the driving restriction policy is considered a reasonable approach for addressing the difficult problems of urban congestion and air pollution. Also, as cities like Beijing are looking for additional policy measures to reduce auto trips to the city, the results from the scenario analysis offer an estimate of the compliance costs by income groups for the different policy options.

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