The effect of dynamic lockdowns on public transport demand in times of COVID-19: Evidence from smartcard data

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ABSTRACT

To tackle the COVID-19 pandemic, Santiago de Chile followed a dynamic lockdown strategy, in which its municipalities were temporarily restricted depending on the degree of advance of the pandemic. We use this variation over time to study the effect of lockdowns on public transport demand, by analyzing a 2019-2020 database of data of trips. Using an empirical strategy that controls for timely variations, we find that dynamic lockdowns reduced public transport demand for all the public transport modes. We also find that this effect varies over time. After the fifth week, its effect starts slowly vanishing, which suggests a short-term effectiveness to reduce transport mobility in this case.

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1. Introduction

The global pandemic caused by the virus SARS-CoV-2, and the subsequent preventive measures, have produced significant changes in the structure of urban mobility worldwide (De Vos, 2020). First of all, increased transport connectivity is a risk factor that may contribute to the dissemination of the disease at the destinations. Besides, there are specific issues concerning shared modes that might be a source of risk during the trip, which increases negative attitudes towards public transport (Sharifi and Khavarian-Garmsir, 2020). These changes have affected many aspects of urban transport systems and patterns, such as a reduction of trips to the Central Business District (CBD), increasing the dispersion of daily activities (Nian et al., 2020); or a reduction of distance travelled (Fatmi, 2020); and a change in traffic accidents (Aloi et al., 2020). However, the main effect of the COVID-19 pandemic has been a reduction of the overall travel demand in every affected city. The most affected mode is public transport, which, independent of the type of sanitary measures taken by governments, has seen a sudden and large reduction of demand due to its perceived risk of contagion (Tirachini and Cats, 2020).

Countries have reacted in different ways to the COVID-19 pandemic regarding mobility restrictions. In Australia, the approach was to adjust the confinement depending on the prevalence of the virus, with increases in the lockdown severity based on the number of daily infections. During the full lockdown, which started on March 30th, the main affected service was public transport, whose demand fell from 15% of the total trips to 7%, replaced mainly by active transport, which increased from 7% to 14% of the total trips, while 15% of the households had not made any changes in their commute nor were planning to do so (Beck and Hensher, 2020). Budapest had a different approach to the pandemic, based on a limited curfew in which people were only able to leave their home for work, shopping, and jogging but without strict enforcement. These measures also have produced a decrease in the share of public transport in urban mobility. While urban mobility was reduced by 51% overall, public transport usage reported an average drop of 80%, with a peak of 90% the second week after the first measure, reducing its participation from 43% to 18% of the total trips (Bucsky, 2020). The Netherlands used a system called "intelligent lockdown", in which people were urged to leave their homes as little as possible. While restaurants, schools, and other "contact professions" were closed, people were allowed to move freely as long as they kept a distance of 1.5 meters to others. This approach reduced the average number of trips per person from 8 to 3.6 trips every three days with a special reduction in public transport use (90%) and car use (80%) (de Haas et al., 2020). Lastly, in Sweden, which used a herd immunity approach, Jenelius and Cebecauer (2020) studied the effect of COVID-19 on public transport in the three largest regions of the country between March and May 2020. They find a decrease of 60% in public transport use in Stockholm while in Västra Göataland the decrease was 40%, with slow increases from mid-April. This decrease has been mainly from a reduction in the number of active public transport travellers as the number of trips per traveller stayed relatively stable. The authors suggest a drastic change of mobility patterns by abandoning public transport and replacing it mainly with private cars and, to some extent, bikes.

For this paper, we count with a large database of smartcard transactions for trips made in the public transport system of the city of Santiago, per mode (bus and metro), location, time, and date. Santiago is composed of 34 municipalities. The Chilean government decided to implement a strategy of "dynamic lockdowns" at the municipality level. These dynamic lockdowns were applied and shifted per municipality on a weekly basis and are, arguably, the more far-reaching non-pharmaceutical governmental measure to reduce virus spreading, as they severely restrict citizens' freedom of movement. Even though there was no random assignment of these lockdowns applied in Santiago, there was an important variation on which municipality was under lockdown each week, creating a quasi-experiment on urban public transport mobility response to the treatment. Besides, we count with a large and granular database of public transport demand constructed from smartcard data at the level of each bus stop, using the methodology developed by Munizaga and Palma (2012), for the years 2019 and 2020. We use this information to model the effects of dynamic lockdown on public transport demand, and control for a series of seasonal and trend factors to identify the effect of dynamic lockdowns. We examine the average effect of dynamic lockdowns, its effect over time, and how it may have affected different municipalities (heterogeneous effect). We find that the strategy of dynamic lockdowns reduces on average the public transport demand in all modes of transport. However, there was a strong temporal effect as dynamic lockdowns have a decreasing effect as time passes. After the fifth week, there are no distinguishable differences compared to non-lockdown municipalities. The results also suggest a dissimilar effect between modes of transport. Results show that bus use fell in a higher proportion than metro use due to the lockdowns. The lockdown also has a heterogeneous effect depending on the socioeconomic characteristics of the municipalities, higher-income municipalities tend to reduce more their use of public transport, as well as municipalities with a higher percentage of elder individuals.

Our research analyses public transport demand trends inferred from smartcard data during the COVID-19 pandemic under lockdown measures. The scientific and policy relevance of this research is twofold. The first lies in contributing to understanding the response of the population to different types of mobility restrictions. Having access to detailed and extensive trip-level public transport demand in a large metropolitan area during this process is a unique powerful tool to analyse the effects of such non-pharmaceutical measures on reducing mobility. We are interested in uncovering both modal and temporal differences in demand adaptation to the new situation. For example, the temporal evolution of public transport demand in a prolonged lockdown could provide evidence about people's reaction to this type of mobility restrictions. In particular, we hypothesise that this type of measure may become less effective over time as restraining people at home for long periods can present several economic and personal difficulties. The second scientific and policy contribution of our work lies in providing evidence of the potential post-COVID situation of public transport systems.In the medium-term, a potentially significant problem for public transport in the post-lockdown period is related to public transport being perceived as poorly adapted to post-pandemic conditions. This perception will create an unhealthy reputation that could be transferred into lower demand levels even when the risk of COVID-19 contagion is heavily reduced or non-existent (Tirachini and Cats, 2020). However, current research points to the use of face masks, ventilation of vehicles while running, and travelling in silence (not talking among passengers) as key elements to greatly reduce the risk of COVID-19 contagion in public transport (Tirachini and Cats, 2020; Moreno et al., 2020). Early evidence on the post-lockdown after the first wave in Europe clearly showed that public transport demand recovered more slowly than car and cycling demand (see, e.g., Orro et al. (2020) for Spain and Joseph Molloy et al. (2020) for Switzerland). A sustained reduction in public transport demand has consequences for the sustainability of mobility patterns, the financial viability of public transport systems, and the social equity of the transport system as a whole (Tirachini and Cats, 2020). Therefore, understanding patterns of public transport demand today could provide glimpses of how the situation will look in the recovery phase and guide public policy responses to restore the role of public transport in satisfying mobility needs in the near future.

The rest of the paper is organised as follows. Section 2 provides background on our case study, including the evolution of the COVID-19 pandemic and the Chilean government response to reduce community contagion. In Section 3, the specific data used for this research is described. Section 4 presents the empirical strategy and the results of the study. In Section 5, discussion and conclusions are presented.

2. The COVID-19 Pandemic in Chile

The first confirmed SARS-CoV-2 case in Chile was announced on March 3rd, 2020 from a citizen coming in a flight from Singapore. The potential risk of the virus and its ease of contagion urged the government to take the first eight measures on March 16th, 2020 (at the beginning of the school year) to contain and mitigate the spread of the virus. The measures included: kindergarten, schools and universities in-person classes suspension; prohibition to visit elderly care centres; restrictions on public gatherings to a capacity limit of 200 people; and compulsory 14 days quarantine for people arriving from foreign countries[1]. Later, on March 22nd, the government declared a daily curfew for the entire country from 10 p.m. to 5 a.m. of the next day. It also recommended private companies to implement remote work when possible and give workplace flexibility to employees[2].

As there is no exact formula to prevent the virus from spreading, almost every country has taken different measures to control it, from following a herd immunity strategy in Sweden (Korhonen and Granberg, 2020), to an aggressive tracking of new cases in Singapore and strict lockdowns in China (Lu et al., 2020). As it was explained before, the main strategy in Chile was known as dynamic lockdowns. This strategy can be defined as local temporary lockdowns, at the municipality or even half-municipality level, depending on the amount of new daily cases, the contagion and positivity rates, and the number of beds available at critical care units in hospitals. During these local lockdowns, people could get out of home only for "essential" activities, such as shopping for groceries and medicines, with a limited number of permits per week, which had to be requested online. The dynamic lockdown strategy was first implemented on March 26th in the city of Santiago, starting with the lockdown of a few municipalities. Then, in the following weeks, the central government decreed new lockdowns in some municipalities and lifted previously established lockdowns in other municipalities. Eventually, given a sharp increase in contagions and deaths attributable to COVID-19 (See Figure 1), a total lockdown for the whole metropolitan area of Santiago started on May 15th[3] and it lasted until July 28th. When the first municipalities were allowed to partially lighten their restriction levels, in the so-called "re-opening" period, people were allowed to leave home only on weekdays. Eventually, at different stages, all municipalities lifted their lockdown, and on September 28th, there were no lockdowns in the city.

In Santiago, private car use has steadily increased in the past decades. For example, between 2001 and 2012, there has been an increase of 41% in the number of households that own at least one car, which goes concurrently with

[1] *Presidente Piñera Anuncia Nuevas Medidas Para Frenar El Avance Del Coronavirus*. (2020, March 15). Gobierno de Chile. https://www.gob.cl/noticias/presidente-pinera-anuncia-nuevas-medidas-para-enfrentar-el-coronavirus/

[2] Guzmán, G. (2020, March 22). *Piñera responde críticas y llama a que empleadores flexibilicen condiciones laborales por Covid-19*. BioBio Chile. https://bit.ly/36LOwsS

[3] Delgado, F. (2020, May 13). *Gobierno endurece medidas y decreta cuarentena para el Gran Santiago y otras 6 comunas de la RM*. BioBio Chile. https://bit.ly/3eENO4N

The effect of dynamic lockdowns on public transport demand

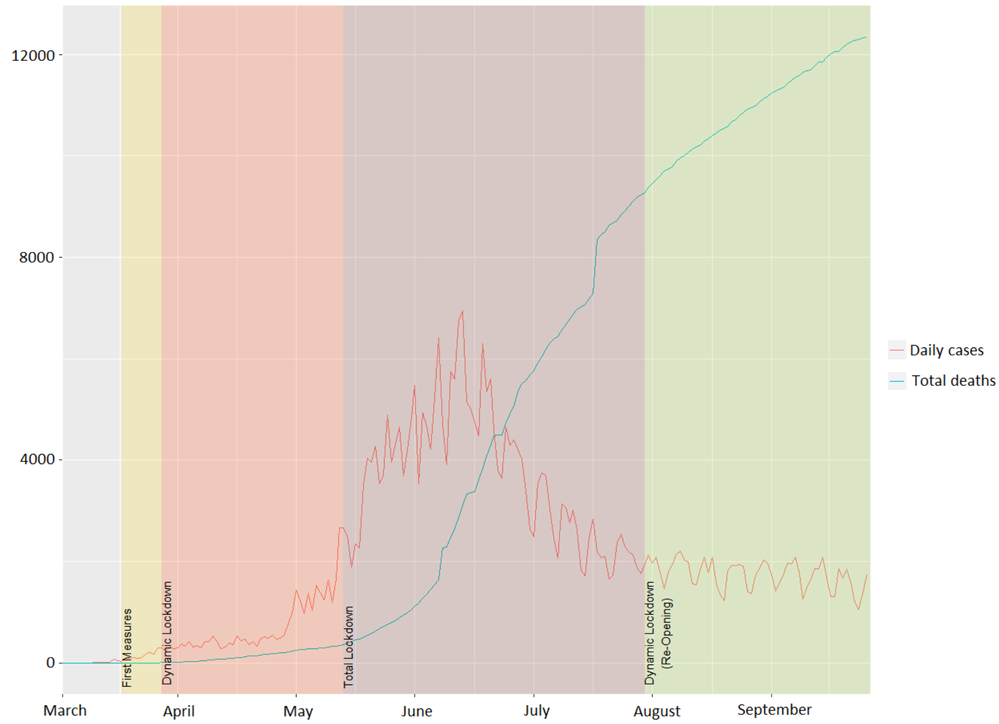

Fig. 1: Daily cases and deaths due to COVID-19 in Chile

a decrease in public transport mode share from 30.1% to 23.7% in the same period (SECTRA, 2014), making Santiago the 7^{th} most congested city in Latin America (26^{th} worldwide[4]). As one of the countries that are part of the Paris climate agreement 2015, Chile has been committed to achieve GHC neutrality by 2050, which implies reducing car use and promoting the use of public transport. Furthermore, the Chilean Nationally Determined Contribution (2020), establishes a commitment to reduce black carbon emissions by at least 25% by 2030, and to decrease private car transport by the transfer to public transport and bicycle. These goals could only be achieved if the country provides better public transport and cycling conditions, that would effectively allow reducing car use in the city. However, the COVID-19 pandemic has generated a trend in the opposite direction.

The first study analysing the impact of the pandemic in urban mobility in the city of Santiago was developed by Astroza et al. (2020), with data collected through an online convenience sample of self-reported trips, focused on mobility during the first week of restrictions, on March 2020. The authors show that public transport is the mode with the largest loss of demand during the pandemic, especially metro usage, and that the reduction in trips is more pronounced for high-income people. They also found other socioeconomic factors that affect the change in public transport use such as education, gender and age, evidencing some of the social implications of the COVID-19 pandemic in the Chilean context. Our research complements the study of Astroza et al. (2020) for the city of Santiago by using extensive and granular reveled preference data inferred from smartcards.

Figure 2 illustrates the lockdown timeline in Santiago, showing different periods of the pandemic from week 1 (From March 23^{th} to

[4]TomTom. (2019). Traffic Index 2019. https://www.tomtom.com/en$_g b/traffic-index/ranking/$

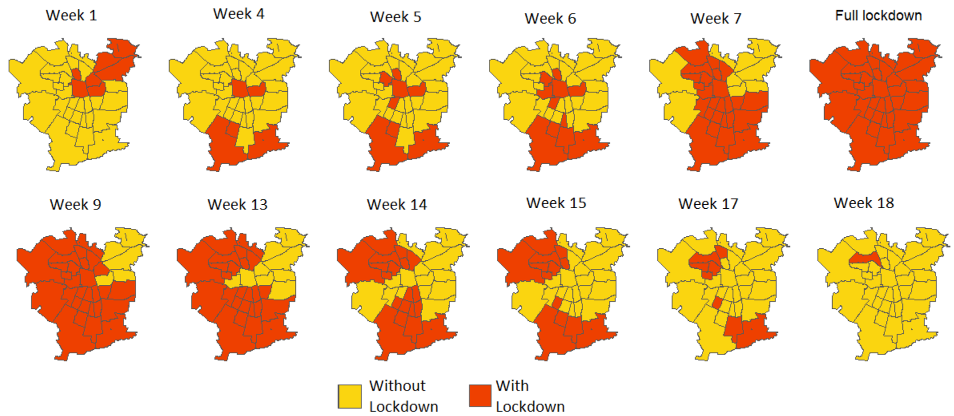

Fig. 2: Changes in lockdown in Santiago by week of lockdown

29^{th}), when the first 7 municipalities entered the lockdown, until week 18 of dynamic lockdown (From September 28^{th} to October 4^{th}) when one last municipality was still on lockdown. The lockdown period in Santiago lasted 28 weeks in total, but as we are interested in identifying the effect of the dynamic lockdowns, we consider as week 9 the first week after the full lockdown is over and so on. The figure includes only some weeks of this period as not every week had seen changes in the spatial distribution of the lockdowns. The figure shows that the first municipalities to enter the lockdown were located at the north-east sector of the city for three weeks. After that period the southern locations started their lockdown followed by the centre and north part of the city. By week 7 most of the city was already under lockdown. It is important to notice that downtown Santiago was the only municipality to be in lockdown from week 1 until full lockdown. The opening period started with the ending of the lockdown for the north-east sector, moving towards the west and, by week 17, the last 8 municipalities were under lockdown. The closing and opening period lasted 8 and 10 weeks respectively.

3. Study Area and Data

To analyse the impact of dynamic lockdowns on public transport demand, this study is conducted in the Santiago Metropolitan area, which is 680 km^2 in size, is compounded of 34 municipalities, and is served by an integrated public transport system known as *Transantiago* (see Munizaga and Palma (2012)). This system includes 382 different bus routes, seven metro lines and a train line (*metrotrén*) which connects the city centre with other localities outside the Santiago Metropolitan Area. All these public transport modes are integrated into a fare system that operates with a pre-paid smartcard (*Bip!*), which is the only payment system available (no cash, no season tickets available). The system as a whole served 5.5 million trips, during a normal day in the pre-Covid period[5]. Observed trips can have up to five trip legs, each associated with a *Bip!* validation upon boarding one of the three modes available: bus, metro and *metrotrén*, the first leg of the trip is paid and the next four are not charged if they are done during the next 90 minutes. The data used in this paper is collected through the platform ADATRAP (Munizaga et al., 2016; Gschwender et al., 2016), which collects the data automatically generated by the daily use of the public transport system including buses location and the validations made by the users, to generate origin-destination

[5] *Información del sistema | Red Metropolitana de Movilidad* http://www.red.cl/acerca-de-red/informacion-del-sistema

matrices, load profiles and bus speed profiles, among other results. These databases contain detailed information for each trip, including trip origin, services used, estimated travel time and destination. For this study, we used the daily trips at municipality level, and from March to September 2019 and 2020. This period captures both closing and opening process of the lockdown in 2020. According to the data, the use of public transport in Santiago has dropped significantly since the beginning of the year.

For the following section, we consider trips during business days and from 5 to 10 a.m. The latter condition is used to capture the morning trip, and avoid return trips. Previous studies show that morning trips enable making the assumption that the origin of the trip is from the municipality of residence of the individual (Amaya et al., 2018). After filtering the data, there are 8122 valid observations which consider the number of daily trips for each municipality. For the socioeconomic characterization of the municipalities, we have used the information from CASEN survey made by the *Ministerio de Desarrollo Social y Familia de Chile* the year 2017.

4. Empirical Strategy and Results

4.1. Average Effects

We begin with a descriptive analysis of the main impact of the COVID-19 pandemic on public transport demand. Figure 3 shows the number of daily public transportation trips per thousand inhabitants for 2019, without the pandemic (in red), and 2020, with the pandemic (in blue). Data from the year 2020 shows an abrupt decline in public transport trips as soon as the government implemented the first measures (mainly, suspension of in-person classes). Daily trips diminished by 72.3% compared to the same weeks in 2019 and 61.3% compared to the last week of "normality" in 2020. Then, demand decreased even more in late-March, when dynamic lockdowns started in the first municipalities. In April, daily trips started to increase rapidly when the government publicly talked about a "new normality" (Basoalto, 2020). Then mobility decreased again at the beginning of May when lockdowns started to affect a large part of the city due to an increase in contagion rates. For the same reason, in mid-May, the authorities determined a lockdown in all municipalities. For this period, Figure 3 shows a low and steady level of daily trips. However, trips started to increase slowly at the end of July, as lockdowns started to be less effective since presumably people got tired of being at home or could not comply with the lockdown anymore due to financial reasons[6] [7]. As authorities slowly lifted lockdowns in municipalities at the end of July, daily trips increased at levels higher than before the first measures started with the pandemic.

To examine the difference of daily trips between municipalities with and without lockdown, Figure 4 shows the average daily public transport trips from municipalities under lockdown compared to those that were not under lockdown on a specific day. Therefore, this figure shows the variation on average daily trips depending on the dynamic lockdowns. Before March 26^{th}, there was no lockdown, and between May 15^{th} and July 28^{th}, all municipalities were under lockdown – i.e., on those periods, there are no differences among municipalities. More importantly, Figure 4 shows that lockdowns reduced the number of public trans-

[6] Agencia Aton. (2020, September 25). *Alcalde de Renca: "La cuarentena hace varias semanas muestra que no es efectiva"* [Newspaper]. 24horas.Cl. https://www.24horas.cl/coronavirus/alcalde-de-renca-la-cuarentena-hace-varias-semanas-muestra-que-no-es-efectiva-4464840

[7] Córdova, M. (2020, July 3). *Hartos de la pandemia: La fatiga emocional y mental que se apodera de la crisis* [Newspaper]. La Tercera. https://www.latercera.com/tendencias/noticia/hartos-de-la-pandemia-la-fatiga-emocional-y-mental-que-se-apodera-de-la-crisis/BNX6TG4KJRASPAFWINFEKGYAGM/

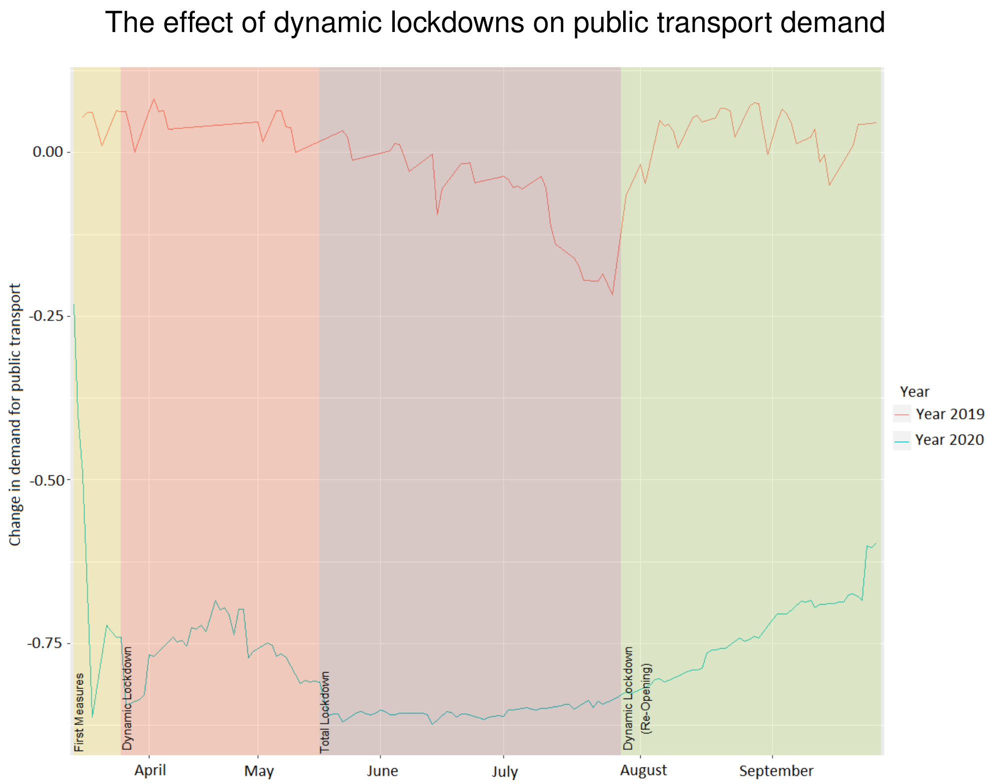

Fig. 3: Average number of trips per thousand inhabitants for 2019 and 2020 (relative to the first two weeks of March)

port trips initially. Then, around the beginning of May, it seems that lockdowns lost effectiveness. An apparent opposite pattern is shown in the first two weeks of August (although when we later control for other variables in the regression models, we did not find a sizable difference).

Because seasonal effects and other factors may confound the previous descriptive analysis, we estimate the effect of dynamic lockdowns on public transportation demand using a regression analysis framework. We take advantage that municipalities under lockdowns varied almost every week, and even some municipalities were under lockdown for a short period, then their lockdown was lifted, and then they went back to be under lockdown. Identification of the effect of dynamic lockdowns stems from within and between municipalities' variation over time – similar to modelling approaches used to evaluate prominent policies (e.g., Araya et al., 2018)[8].

Equation 1 shows the main model:

$$\ln(V_{it}) = X_{it}\beta + \tau L_{it} + \gamma C_t + \epsilon_{it} \qquad (1)$$

where V_{it} is the ratio of the number of trips performed on all public transport modes over the total population for municipality i during day t, L_{it} indicates whether municipality i is under lockdown on day t (=1, 0 if not), C_t indicates whether first measures decreed by the government started (=1 after March 15^{th}, 0 before), X_{it} includes year, month and weeks fixed effects, day-of-the-week dummies, and municipalities fixed effects to control for municipalities' time-invariant characteristics. ϵ_{it} is the error term. We use robust standard errors clustered at the

[8] This model is similar to a difference-in-difference approach, in which a treated group is compared over time to a non-treated group. However, in our case, treated units (i.e., municipalities under lockdown) changed over time providing a greater sort of variation to examine the effect of lockdowns – a municipality can be under lockdown one day and without lockdown in another.

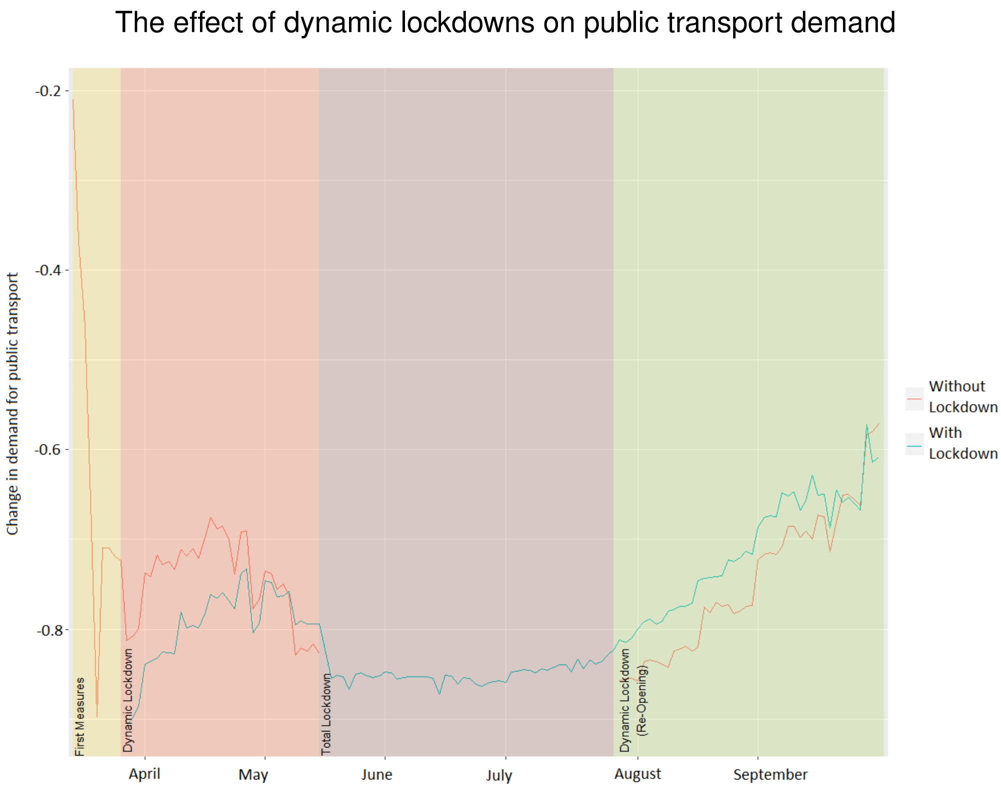

Fig. 4: Average number of trips per thousand inhabitants for municipality-day with and without lockdown (relative to the first two weeks of March)

municipality level (see Bertrand et al., 2004). The average treatment effect of dynamic lockdowns is provided by τ, which, given that the dependent variable was modelled using natural logarithm, it can be approximately interpreted as a percentual variation of V_{it} when the estimate is small (if not, interpretations come from using one minus the exponential of the coefficient).

Table 1 shows the estimated effect of dynamic lockdowns on public transport demand using Equation 1, for three models. Model I only considers L_{it} and no controls for the first measures implemented neither the time fixed effects. Model II adds C_t and Model III also includes time fixed effects (all models include municipalities fixed effects). Results show that there is a significant impact of the lockdown in the use of public transport. Without any control variable, the Model I shows that trips decreased by 70.3% (from $1 - \exp(\beta)$) compared to the year before. However, as shown by Model II, most of this massive effect comes down to 21.8% when accounting for the first measures applied at the beginning of the COVID-19 pandemic (including school closures and voluntary mobility restrictions), which after a few weeks coincide with dynamic lockdowns. In Model III, controlling for any difference correlated to timely effects, the average and overall effect of dynamic lockdowns is a reduction of 12.1% of daily trips. As a reference, de Grange and Troncoso (2011) reported a 5.5% decrease in private car use due to environmental restrictions imposed in Santiago in 2008. The Time Fixed Effect includes a year dummy to control for the evasion and other effects due to the social unrest on October 2019.

Table 2 shows the effect of dynamic lockdowns by mode (i.e., trips using only metro, only bus, and intermodal trips combining bus and metro). For this, we used Equation 1 but define V_{it} as the ratio of the number of trips on each respective mode. We control for the first measures and the time fixed effects. Results show that the effect of first measures was larger for metro than

Table 1
Dynamic lockdowns average effect.

	I	II	III
Lockdown	-1.214***	-0.218***	-0.129**
	(0.043)	(0.036)	(0.036)
	<0.001	*<0.001*	*<0.001*
First Measures		-1.550***	-1.318***
		(0.048)	(0.054)
		<0.001	*<0.001*
Time Fixed Effects	No	No	Yes
Observations	5470	5470	5470

$^{+}$ $p < 0.10$, * $p < 0.05$, * $p < 0.01$, ** $p < 0.001$
All columns show robust standard errors between parenthesis and *p*-values in italic.

for buses, in line with what is reported by Astroza et al. (2020).

Regarding lockdowns, trips by all public transport modes suffered a reduction, but the effect was larger for the buses (25.2%) than for the metro (10.6% - 12.1%)[9]. This dichotomy may be explained in part by socioeconomic differences. Metro users were more likely to switch to other travel modes (e.g., cars or bikes) or to work from home, as they have a higher income than average bus users SECTRA (2014), and likely reacted quicker to the first measures that included voluntary confinement. On the contrary, bus users with lower income may be forced to travel and would stop doing so only when lockdowns were in place. Additionally, as metro users already experienced a large reduction in trips with the decree of the first measures, it becomes more difficult for that mode to reduce its levels even further. A second reason behind this finding is that fare evasion on buses may have been larger for the lockdown period due to a policy enacted in late March 2020 that required bus passengers to board buses through rear doors to minimise close contact with drivers[10], while the metro did not see any change on its low fare evasion rates.[11].

Table 2
Dynamic lockdowns average effect by modes of transport.

	I	II	III
	Bus	Metro	Bus & Metro
Lockdown	-0.290***	-0.112**	-0.130**
	(0.036)	(0.039)	(0.037)
	<0.001	*0.009*	*0.001*
First Measures	-1.107***	-1.428***	-1.453***
	(0.043)	(0.080)	(0.060)
	<0.001	*<0.001*	*<0.001*
Time Fixed Effects	Yes	Yes	Yes
Observations	5355	3893	5466

$^{+}$ $p < 0.10$, * $p < 0.05$, * $p < 0.01$, ** $p < 0.001$
All columns show robust standard errors between parenthesis and *p*-values in italic.

4.2. Effect Over Time

The previous analysis showed a relevant average effect associated with the dynamic lockdowns. To examine how this effect varies over time – which should be relevant based on Figure 4 –, we estimate the dynamic lockdown's weekly effect based on Equation 2.

$$\ln(V_{it}) = X_{it}\beta + \tau L_{it} + \sum \rho_j T_{tj} \times L_{it} + \sum \alpha_j T_{tj} + \gamma C_t + \epsilon_{it} \quad (2)$$

where, in addition to the variables defined in Equation 1, T_{tj} indicates whether day t belongs to dynamic lockdown week j (= 1, 0 if not), from the first week of dynamic lockdown (j = 1) to the last week of dynamic lockdown (j = 17). This variable is included as interaction with L_{it} to examine the effect of lockdown overtime, and as main effect to control for the effect over time not associated with a municipality being in lockdown. Our estimate of interest is ρ_j,

[9] This data analysis excludes the weeks that all municipalities were under lockdown (the "total lockdown" phase, because it does not provide any variation). For completeness, Appendix 1 shows results, including these weeks. The effect of dynamic lockdown is overestimated, as expected, as when all municipalities were in lockdown, the number of trips was very low.

[10] Fernández, O. (2020, March 31). Pasajeros deberán ingresar por puertas traseras de los buses para proteger a conductores [Newspaper]. La Tercera. https://www.latercera.com/nacional/noticia/pasajeros-deberan-ingresar-por-puertas-traseras-de-los-buses-para-proteger-a-conductores/V3MPSVFG7RFV3MRFVDLKXWHRDQ/

[11] In Santiago, trips that include bus metro use the same fare, so there is no incentive to evade.

which indicates the average treatment effect of the dynamic lockdown for each week.

Figure 5 shows ρ_j for each week. It indicates that the effect of dynamic lockdowns on public transport demand decreases after a few weeks. In the first week, municipalities in lockdown had 59.0% fewer trips than municipalities not in lockdown. This difference started to shrink every week. For example, in the fourth week, municipalities in lockdown had 20.7% fewer trips than those not in lockdown. After the sixth week, there was almost no sizable difference[12]. This result is consistent with data, based on connection to telecommunication infrastructure, showing that people' mobility increase after several weeks of lockdown (Olivares et al., 2020). The hypotheses behind this result are multiple: financial, social or personal needs. Several behavioural changes reflected this greater mobility despite lockdowns: some businesses started to open as "sellers of essential products" (Sepúlveda et al., 2020), starting on April 17^{th}, 2020 public employees had to go back to work in their offices, and people started to use more permits[13].

The estimated trend in public transport demand due to the lockdowns has to be seen with caution because, even though there is sufficient variation across and within municipalities, the dynamic lockdown order was not random. For example, the effect may be triggered by the fact that the wealthier municipalities, in the north-east part of the city, were the first be affected by lockdown at the beginning of the dynamic lockdown strategy. Therefore, the estimated effect reflects a particular form of dynamic lockdown correlated to municipalities' characteristics. Also, north-east municipalities were the first ones to have their lockdown lifted in the opening phase. Households in these municipalities can more easily substitute public transportation, work from home, and do online shopping (SECTRA, 2014). Lastly, some burned metro stations after the social unrest started reopening during the dynamic lockdown period, this impact can be seen in Appendix 2 where the demand for metro recovered faster than the demand for bus. This issue is explored in the analysis of heterogeneous effects, presented next.

4.3. Heterogeneous Effect

We examine heterogeneous differences associated with the dynamic lockdowns, by results by age and income, since those variables have shown to be relevant factors related to risk perception and COVID-19 contagion (Mondschein et al., 2020). For this, we use municipalities' characteristics based on the proportion of the elderly population (over 65 years old), income per capita (average US$ in thousands using the 2019 conversion rate), and the population's proportion under the poverty line. Similar to Equation 1, we estimate:

$$\ln(V_{it}) = X_{it}\beta + \tau L_{it} + \sigma L_{it} \times S_i + \gamma C_t + \epsilon_{it} \quad (3)$$

where we add S_i, which indicates the socioeconomic variables described above (elderly, income per capita and poverty) interacted with the term L_{it}. Therefore, σ indicates the heterogeneous effect of dynamic lockdowns[14]. Results are shown in Table 3.

Table 3 shows that municipalities' reduction of public transport demand associated with the dynamic lockdown is more pronounced in municipalities with a larger proportion of the elderly population. This result was expected be-

[12] We have excluded week 18 of the analysis that included only the first two days of the week with one municipality under lockdown.

[13] *Permisos temporales suben 25% pero se mantienen bajo el millón en la previa del primer fin de semana de la RM en desconfinamiento.* (2020, October 3). La Tercera. https://www.latercera.com/nacional/noticia/permisos-temporales-suben-25-pero-se-mantienen-bajo-el-millon-en-la-previa-del-primer-fin-de-semana-de-la-rm-en-desconfinamiento/6E4ZGLT54ZHBFFO7OTWP7B25DM/

[14] The main effect of S_i is captured by the municipalities' fixed effect.

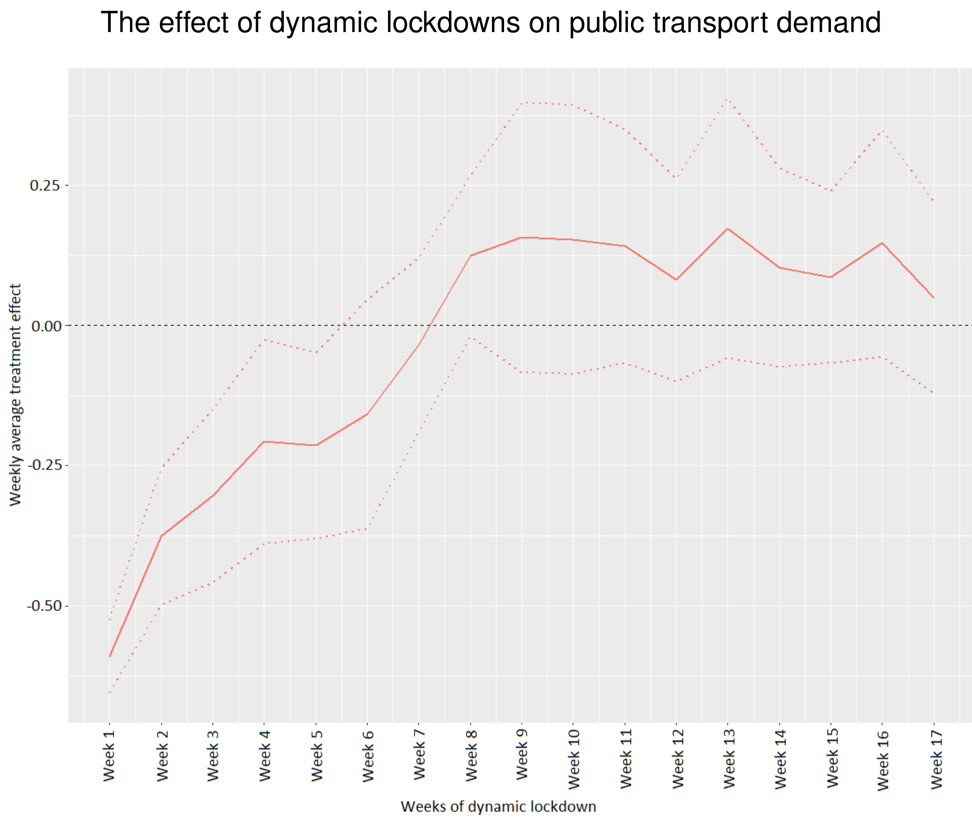

Fig. 5: Lockdown's weekly average effect in public transport

cause older people have a higher risk of contagion and get seriously ill, as well as younger people living with elders may have tried to avoid trips that may have spread the disease at home. In addition, the elderly population can have more flexible hours, and people over 75 years old were requested to be at home from the start of the first measures, regardless of their place of residence. Table 3 also shows the differences in socioeconomic characteristics. In municipalities with a higher income per capita and lower poverty level, dynamic lockdowns reduce more public transport demand than in municipalities with a lower income per capita and higher poverty level. As mentioned above, higher-income municipalities have more alternatives to replace public transport, work from home, or bear a job loss than people living in poorer municipalities.

5. Discussion

During the year 2020, city lockdowns have been used to control the Covid-19 pandemic worldwide. In Chile, this measure was implemented dynamically, at the municipality level, depending on how the prevalence of the virus in the community evolved over the weeks. This variation in time and space created a quasi-experiment on urban public transport mobility response to the lockdowns, which we study by examining smartcard transaction data from Santiago's public transport system from 2019 and 2020. We complement the analysis by examining the correlation between sociodemographic attributes (such as average income and proportion of elderly people per municipality) and the effectiveness of dynamic lockdowns. Besides allowing the analysis of the success of dynamic lockdowns, our study also gives some insights on the long-term implications that the COVID-19 pandemic may have for public transport de-

Table 3
Dynamic lockdowns heterogeneous treatment effect.

	I Elderly	II Income	III Poverty
Lockdown	0.144	0.038	-0.344***
	(0.152)	(0.086)	(0.095)
	0.351	*0.658*	*0.001*
First Measures	-1.319***	-1.333***	-1.328***
	(0.055)	(0.057)	(0.056)
	<0.001	*<0.001*	*<0.001*
Elderly × Lockdown	-0.020*		
	0.01		
	0.045		
Income × Lockdown		-0.160*	
		0.059	
		0.010	
Poverty × Lockdown			0.011*
			0.005
			0.042
Time Fixed Effects	No	No	Yes
Observations	5470	5470	5470

$^{+}$ $p < 0.10$, * $p < 0.05$, * $p < 0.01$, ** $p < 0.001$
Elderly and poverty are measured as the percentage of people over 65 years old and below the poverty line in a municipality, respectively. Income is measured as the average income in a municipality in US Dollars. All columns show robust standard errors between parenthesis and *p*-values in italic.

mand.

We distinguish between two main actions affecting the public transport demand during the analysis period: the first measures implemented by the government at the beginning of the pandemic (mainly in-person classes suspension and voluntary confinement), and the effect of dynamic lockdowns implemented at municipality level. First measures reduced the use of public transport by 72.3%, relative to the year 2019 (without COVID), while the lockdowns reduced, on average, the public transport demand by 12.1%.

When we separated our results by mode, results show that the first measures had a higher reduction on the use of metro than on the use of buses. We hypothesize that this finding has to do in part with the socioeconomic characteristics of metro users, who have a higher average income compared to bus users, and therefore, more possibilities to avoid travelling by public transport (e.g., to work from home, to resort to e-commerce, to travel by private car) when first measures that include voluntary confident were implemented. Another possible explanation for this finding is a potential higher perceived risk of contagion when travelling in an underground closed space. On the other hand, results also shown that, on the contrary, the effect of the dynamic lockdowns was stronger for buses than for metro and bus metro combined (-25.2%, -12.2% and -10.6% demand drops, respectively). The main explanation for this finding is also socioeconomic. Since bus users have a lower income, they have a smaller chance to be able to respond to the voluntary confinement implied by the first measures, and only formal lockdowns effectively prevented them from travelling, resulting in a relatively larger effect on buses. Another explanation behind this finding may be related to fare evasion for buses in the lockdown period, which was estimated to increase by 10% on the pandemic period [15], which would imply a reduction of 66.9% in the use of buses due to the pandemic.

Analysing the weekly dynamic lockdown effect, we find a temporal effect of the lockdowns in public transport. As the weeks pass by, we can see a decrease of the average effect as the municipalities start slowly recovering their public transport demand to pre-lockdown levels and the effect on the new municipalities in lockdown is lower than the first ones.

The lockdown approach to the pandemic has divided opinions on its adequacy to fight the virus and its long-term consequences. As of today, many countries have seen a second peak, or even a third peak, of contagion of the virus, forcing its population to re-enter lockdowns. This paper contributes to understanding the changes in people's behaviour towards public transport and helps to generate relevant information for policymakers in the use of different strategies in a future resurgence of the virus. As we es-

[15] http://www.fiscalizacion.cl/wp-content/uploads/2016/10/Evasion-Ene-Mar-21.pdf

timate, generalised lockdowns have limited efficiency in reducing public transport demand if prolonged over several months, finding a tendency to equalise to pre lockdown levels as weeks goes by (but not to pre-pandemic levels). Nevertheless, our results also suggest that the shock effect of the measure is significant during the first weeks, and therefore, we can hypothesise that it could be successful in reducing mobility if it is used for limited periods of time. We also found that the lockdown effect seems to remain after this measure is over, without a full temporal recovery. This suggests that, if this tendency continues after the pandemic, there may be a long way until we can see public transport reaching pre-pandemic demand levels.

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Appendix

Appendix 1: Dynamic lockdowns average effect including full lockdown effect.

	I	II	III	IV
	All Modes	Bus	Metro	Bus & Metro
Lockdown	-1.388***	-1.172***	-1.493***	-1.531***
	(0.057)	(0.046)	(0.081)	(0.061)
	<0.001	<0.001	<0.001	<0.001
First Measures	-0.268***	-0.418***	-0.234***	-0.259***
	(0.034)	(0.033)	(0.033)	(0.035)
	<0.001	<0.001	<0.001	<0.001
Time Fixed Effects	Yes	Yes	Yes	Yes
Observations	8122	7954	5733	8118

$^{+}$ $p < 0.10$, * $p < 0.05$, * $p < 0.01$, ** $p < 0.001$

All columns show robust standard errors between parenthesis and *p*-values in italic.

Appendix 2: Lockdown's weekly average effect in public transport