Evaluating the impact of emerging technologies on urban accessibility by public transport

Evidence from QR payment and real-time information in Santiago, Chile

Authors: Carla Olivares, **Jacqueline Arriagada**, Daniel Schwartz, Marcela Munizaga.

Agenda

1. Motivation and research gap
2. Case and data
3. Methodology
4. Results and implications


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Accessibility

Accessibility represents people's
ability to reach the activities required in their daily lives

This study tests whether digital tools impact in public transport accessibility.

If real-time information and mobile payment allow people to make better travel decisions, it may increase effective accessibility.

Q1: Are QR-based payment and official real-time information associated with accessibility to education and employment?

Q2: Are these associations spatially equitable, or do they reproduce territorial inequalities?

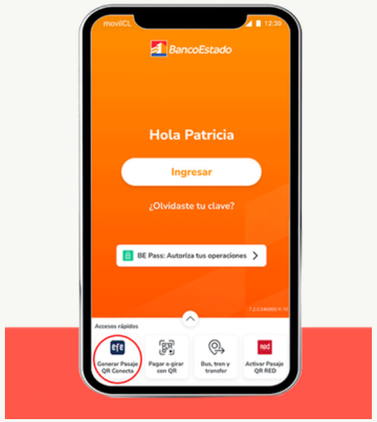
Case study

Public transport in Santiago: different payment methods

Smartcard bip!

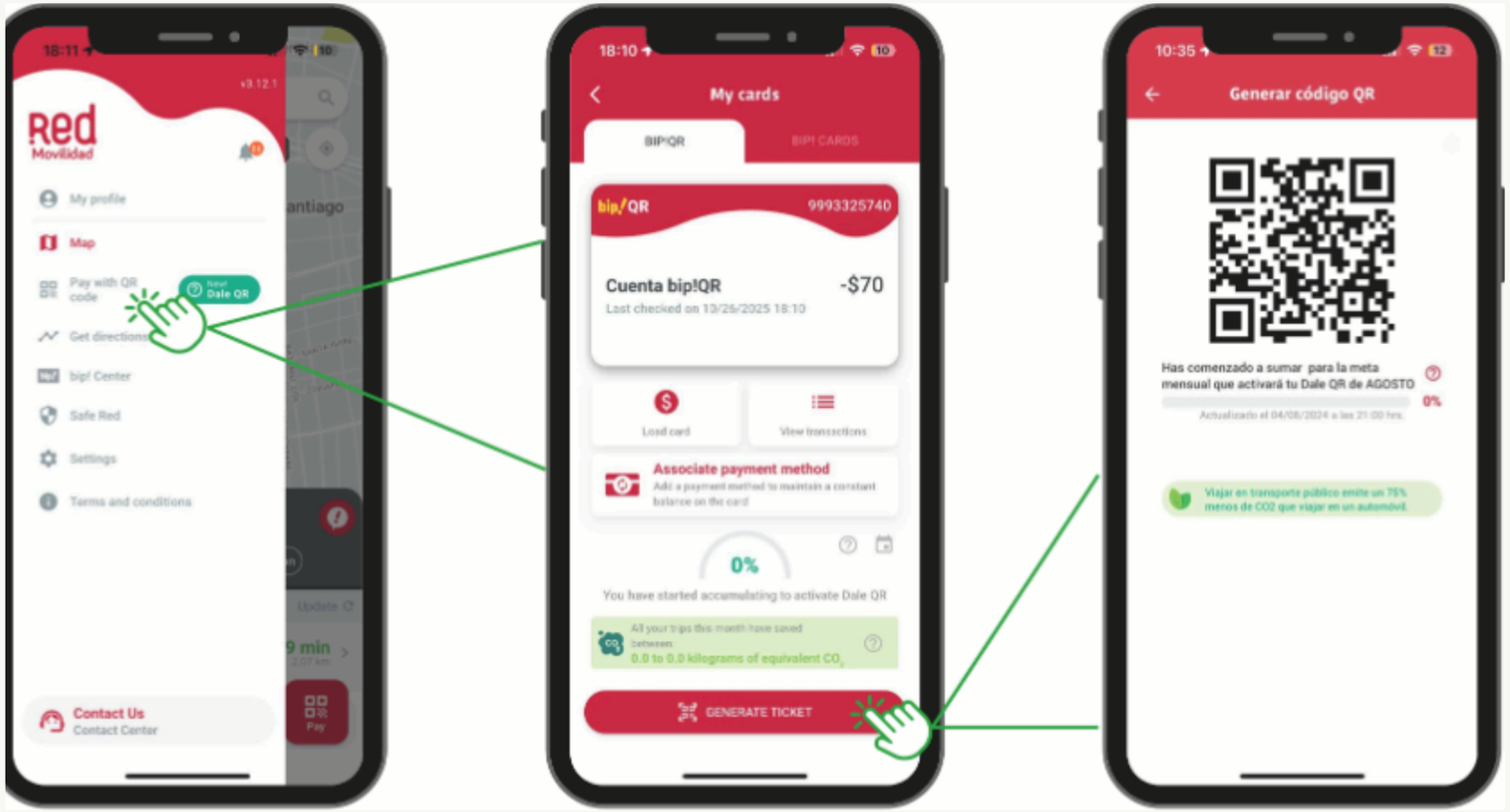
Red Movilidad QR

Fintech QR



Digital payment interface

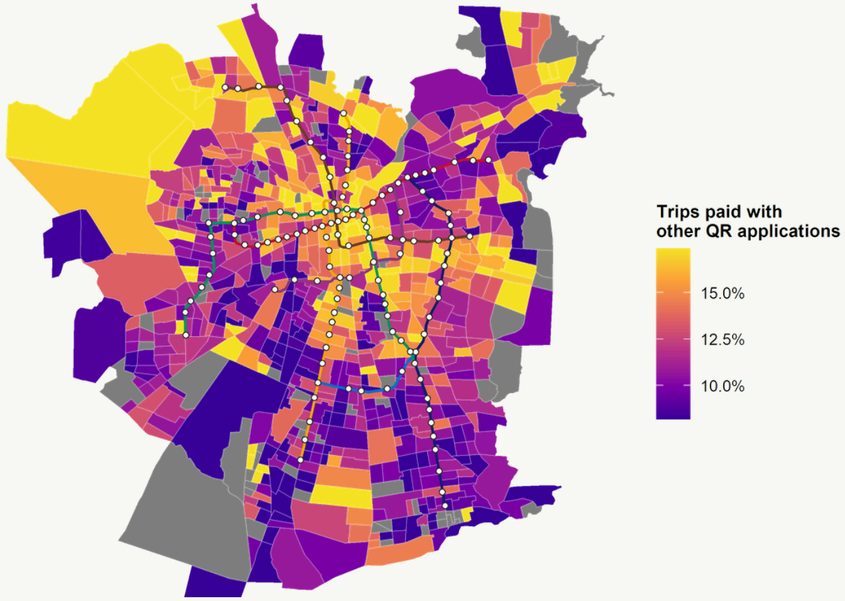
Public transport in Santiago: different payment methods



Central empirical distinction: Red Movilidad QR is a proxy for the official information ecosystem, not only for digital payment.

QR adoption is not homogeneous across Santiago

Share of trips paid with fintech QR by zone



Fintech QR: more distributed across the metropolitan area.

Share of trips paid with Red Movilidad QR by zone

Red Movilidad QR: more concentrated in eastern areas.

Methodology

DATA

The study combines passive mobility data, opportunities, and territorial controls.

Data block	Main variables	Source
Trips	OD, travel-time components, transfers, payment method, date and time	Red Movilidad Trip Table / DTPM, 2024-2025
Transport supply	Schedules, frequencies, stops, stations, service indicators	GTFS, load profiles, Operations Program / DTPM
Opportunities	Early-childhood and primary education; employment-related establishments	Chilean Ministry of Education; Chilean Internal Revenue Service (SII); Google Maps API
Controls	Population, income, employment, age, car ownership, socioeconomic characteristics	Chilean Census; OD Survey

Scope: April 2024 and April 2025, weekdays, morning peak 5:00-9:00, disaggregated to origin zones.

ACCESSIBILITY INDICATOR

Accessibility is measured with a normalized gravity-based indicator (Hansen, 1959).

Accessibility = $$A_i^{k,n,t,s} = \frac{\sum_j D_j^k \exp\left(-\lambda_s c_{ij}^{n,t,s}\right)}{\sum_j D_j^k}$$

A_i (Accessibility)

Is the accessibility for each origin zone i, opportunity type k, payment method n, year t, and travel-time specification s

D_j (Oportunities)

is the number of opportunities of type k (laboral or educational) in destination zone j

c_ij (cost of travel)

Average travel time between i and j for payment method n in year t and travel time specification s (observed and generalized)

λ (decay parameter)

The decay parameter λ is set to 0.045 for observed travel time and 0.039 for generalized travel time

The indicator measures the proportion of all opportunities in the city that are effectively accessible from a given area, considering that more distant opportunities contribute less.

Generalized travel time captures the burden of the trip

Observed travel time counts minutes.

Generalized travel time gives extra weight to waiting, walking, transfers, and in-vehicle time.

T_gen = 1.9 initial wait + 1.3 transfer wait + 3.19 walking + 13.5 transfers + 1.0 in-vehicle time

MODEL

OLS models estimate to conditional associations

Accessibility = Red QR share + Fintech QR share + controls + year FE + commune FE

$$A_i^{k,t,s} = \alpha + \beta_1 QR_{it}^{\text{Red}} + \beta_2 QR_{it}^{\text{Oth}} + \mathbf{X}_{it}'\gamma + \delta_t + \mu_c + \varepsilon_{it}$$

Dependent variable

Accessibility to education or employment, using observed or generalized travel time.

Key predictors

Share of trips paid with Red movilidad QR and share paid with Fintech QR in each origin zone.

Controls

Sociodemographic, territorial, and service variables; clustered standard errors.

Additional models test macrozone fixed effects and territorial heterogeneity

Results

Model Results: Education Accessibility

Accessibility = Red Movilidad QR share + Fintech QR share + controls + year FE + commune FE

Outcome	Observed travel time	Generalized travel time	Observed travel time + fixed effects	Generalized travel time +fixed effects	Interpretation
Share of trips with Red Movilidad QR	2.992e-04***	2.887e-04***	2.677e-04***	2.439e-04***	one aditional percentage point increase in 0.5 weighted establishments
Share of trips with Fintech QR	8.630e-05*	5.128e-05+	7.782e-05*	4.770e-05	smaller / less robust
Share of trips with Red Movilidad QR	1.345e-03***	1.177e-03***	1.009e-03***	8.508e-04***	46-55 weighted employment establishments
Share of trips with Fintech QR	1.558e-05	-5.627e-05	-1.901e-05	-7.921e-05	not significant

This change represents an increase of about
2.9–3.6% relative to the average level of educational accessibility

Model Results: Education Accessibility

Accessibility = Red Movilidad QR share + Fintech QR share + controls + year FE + commune FE

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Model Results: Employment Accessibility

Accessibility = Red Movilidad QR share + Fintech QR share + controls + year FE + commune FE

Outcome	Observed travel time	Generalized travel time	Observed travel time + fixed effects	Generalized travel time +fixed effects	Interpretation
Share of trips with Red Movilidad QR	2.992e-04***	2.887e-04***	2.677e-04***	2.439e-04***	one percentage point increase in 0.5 weighted establishments
Share of trips with Fintech QR	8.630e-05*	5.128e-05+	7.782e-05*	4.770e-05	smaller / less robust
Share of trips with Red Movilidad QR	**1.345e-03*** **	**1.177e-03*** **	**1.009e-03*** **	**8.508e-04*** **	**46-55 weighted employment establishments**
Share of trips with Fintech QR	1.558e-05	-5.627e-05	-1.901e-05	-7.921e-05	not significant

This change represents an increase of about 5.2% –6.2% relative to the average level of employment accessibility.

Model Results: Employment Accessibility

Accessibility = Red Movilidad QR share + Fintech QR share + controls + year FE + commune FE

Outcome	Observed travel time	Generalized travel time	Observed travel time + fixed effects	Generalized travel time +fixed effects	Interpretation
Share of trips with Red Movilidad QR	2.992e-04***	2.887e-04***	2.677e-04***	2.439e-04***	one percentage point increase in 0.5 weighted establishments
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Share of trips with Red Movilidad QR	**1.345e-03*** **	**1.177e-03*** **	**1.009e-03*** **	**8.508e-04*** **	**46-55 weighted employment establishments**
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MODEL HETEROGENEITY

Interaction effects between Macrozones and Red Movilidad QR on Educational Accessibility

Interaction: Macrozone x Red Movilidad QR	Educational Accessibility	Employment Accessibility
Share of trips with Red Movilidad QR	3.552e-04	2.214e-03*
North	-3.927e-04	-2.213e-03*
East	1.293e-04	-7.974e-04
West	-1.916e-04	-1.716e-03+
South	-3.206e-04	-2.006e-03*
Southeast	1.351e-04	-6.719e-04

Education

Interactions are not statistically significant, so the Red Movilidad QR association is relatively stable across macrozones.

MODEL HETEROGENEITY

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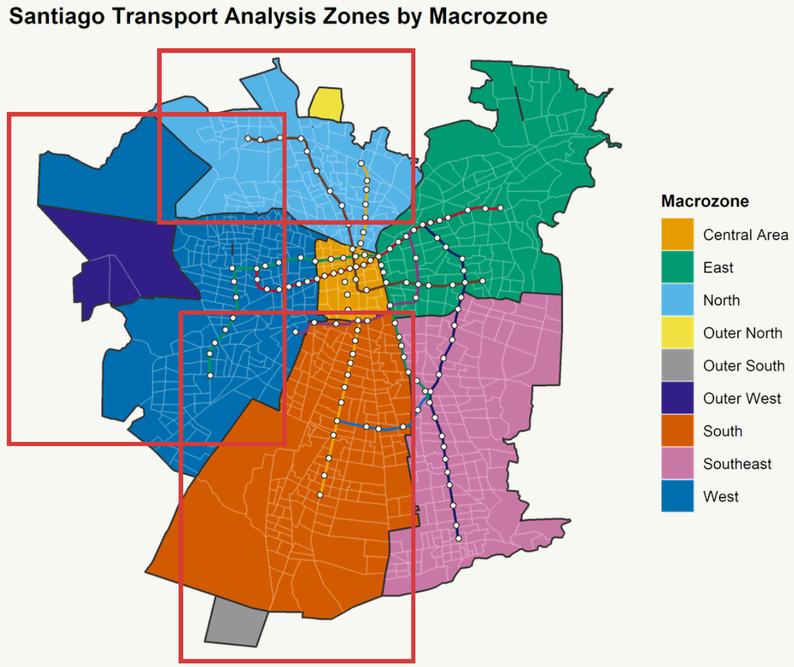

Employment

North, West, and South show smaller Red Movilidad QR associations than the Central Area.

Summary

Red Movilidad QR is positively associated with accessibility to both education and employment.

Fintech QR shows a positive association with education accessibility, but no statistically significant association with employment accessibility.

These findings suggest that the relevant mechanism is the combination of payment and official real-time information, rather than digital payment alone.

Summary

For education accessibility, we do not find significant spatial variation across macrozones.

For employment accessibility, we find significant spatial variation. The effect of QR RED is smaller in peripheral macrozones, particularly in the north, south, and west of Santiago.

This suggests that digital tools improve accessibility, but their benefits still depend on the underlying transport network.

Digital tools can enhance service quality and improve access to opportunities

1. Build integrated public platforms: Combine payment, real-time information, trip planning, and service updates.

2. Improve public transport service: Digital tools are most effective when supported by high-quality service and infrastructure.

3. Protect digital inclusion: Expand access to digital mobility tools across all territories and population groups.

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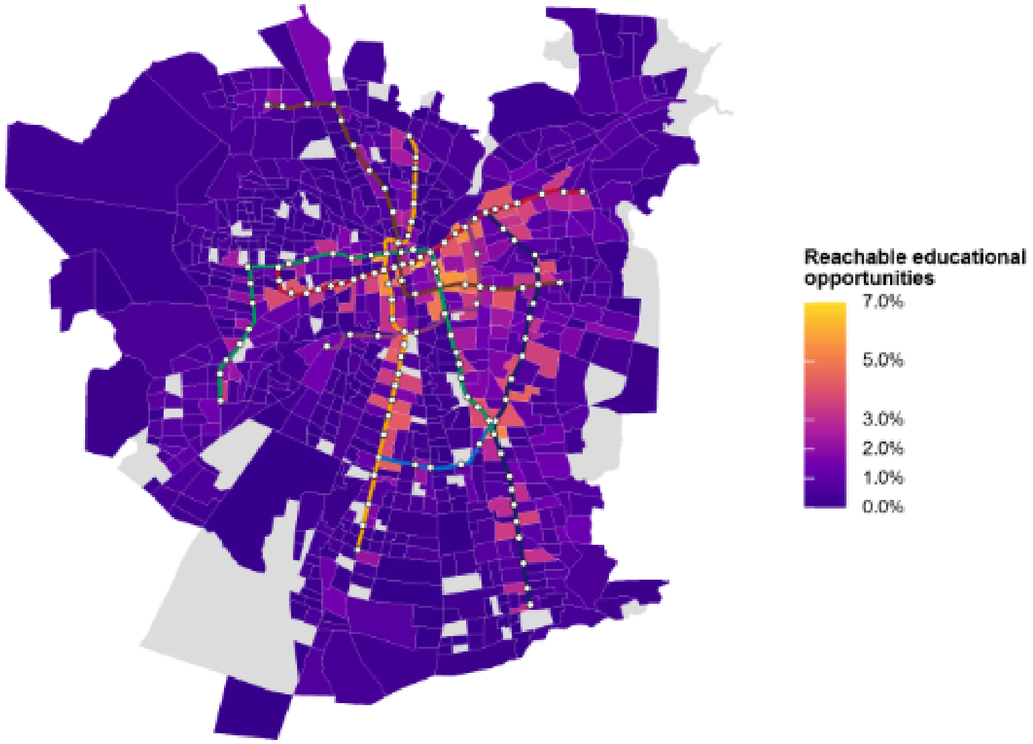
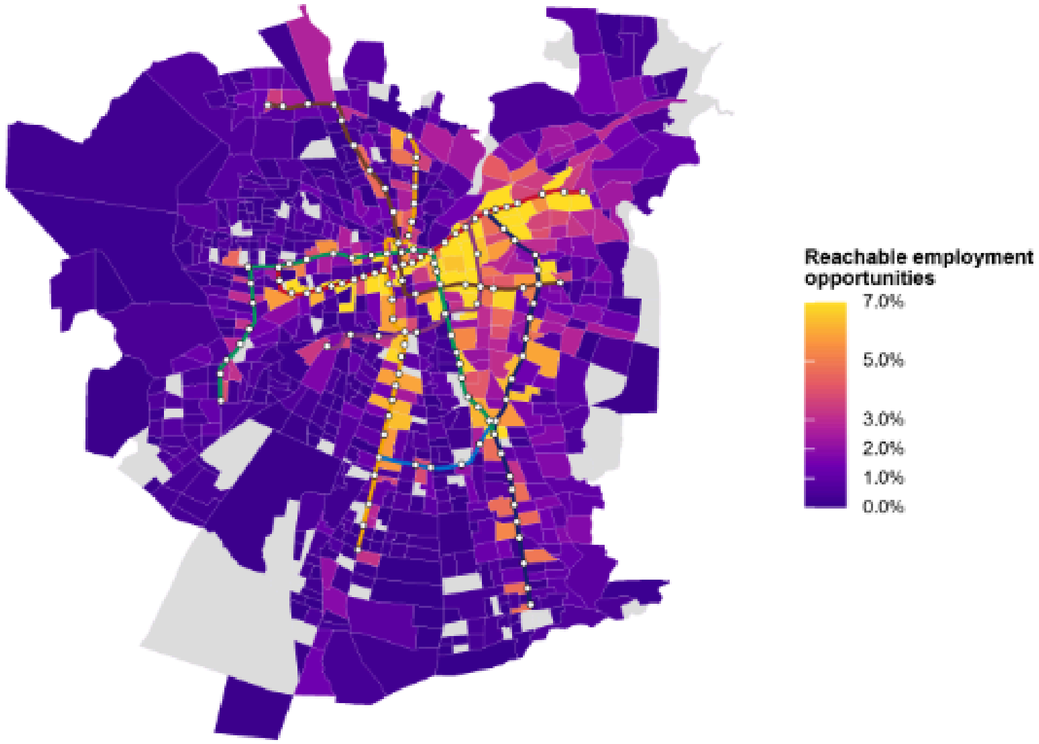
Before payment methods, access to opportunities is already unequal.

Educational Accessibility

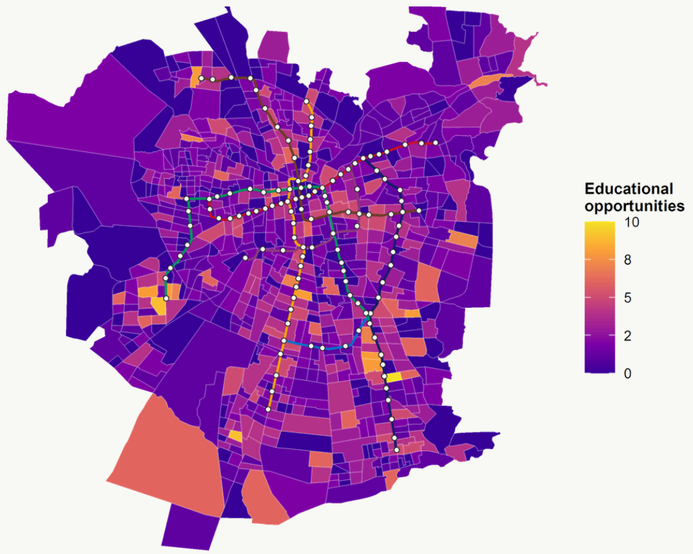


Job Accessibility

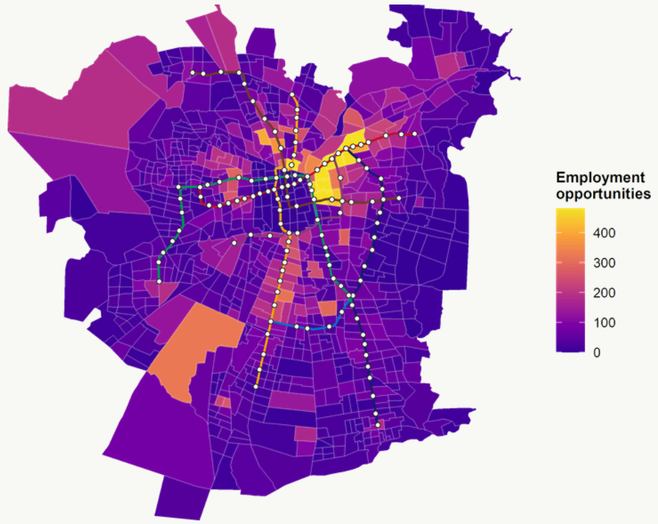


Why Red Movilidad QR associations differ across territories

Educational opportunities



Employment opportunities



Transport supply by macrozone

Average services per zone and Metro stations

Macrozone	Services/zone	Metro stations
Central Area	5.73	19
North	4.40	16
Southeast	4.32	24
South	4.17	17
East	3.98	29
West	3.87	21

References

Ait-Ali, A., Peterson, A., 2025. Assessing the effects of traffic information to passengers: a literature review. Transportation Research Procedia 82,24–42. URL: https://www.sciencedirect.com/science/article/pii/S2352146524003247, doi:https://doi.org/10.1016/j.trpro.2024.12.026. world Conference on Transport Research - WCTR 2023 Montreal 17-21 July 2023.

Anderson, M.K., Nielsen, O.A., Prato, C.G., 2017. Multimodal route choice models of public transport passengers in the greater copenhagen area.
EURO Journal on Transportation and Logistics 6, 221–245.

Aprigliano, V., Toro, C., Rojas, G., Barros, G., Fukushi, M., Seriani, S., 2024. Effects of the built environment and sociodemographic factors onaccessibility in the city of valparaíso, chile. Journal of Transport Geography URL: https://doi.org/10.1016/j.jtrangeo.2024.103931,doi:10.1016/j.jtrangeo.2024.103931.

Arriagada, J., Guevara, C.A., Munizaga, M., Gao, S., 2025a. An experiential learning-based transit route choice model using large-scale smart-carddata. Transportation 52, 1543–1568.

Arriagada, J., Munizaga, M.A., Guevara, C.A., Prato, C., 2022. Unveiling route choice strategy heterogeneity from smart card data in a large-scalepublic transport network. Transportation Research Part C: Emerging Technologies 134, 103467. doi:10.1016/j.trc.2021.103467.

Arriagada, J., Prato, C., Munizaga, M., 2025b. Incorporating the inertia effect into a route choice model using fare transaction data from a large-scalepublic transport network. Transportation Research Part A: Policy and Practice 196, 104467.

Basso, F., Frez, J., Martínez, L., Pezoa, R., Varas, M., 2020. Accessibility to opportunities based on public transport gps-monitored data:The case of santiago, chile. Travel Behaviour and Society 21, 140–153. URL: https://doi.org/10.1016/j.tbs.2020.06.004,doi:10.1016/j.tbs.2020.06.004.

Bivina, G.R., Gupta, A., Parida, M., 2020. Walk accessibility to metro stations: An analysis based on meso- or micro-scale built environment factors.Sustainable Cities and Society 55, 102047. doi:10.1016/j.scs.2020.102047.

Boisjoly, G., Moreno-Monroy, A.I., El-Geneidy, A., 2017. Informality and accessibility to jobs by public transit: Evidence from the sãopaulo metropolitan region. Journal of Transport Geography 64, 89–96. URL: https://doi.org/10.1016/j.jtrangeo.2017.08.005,doi:10.1016/j.jtrangeo.2017.08.005.

Brakewood, C., Ziedan, A., Hendricks, S.J., Barbeau, S.J., Joslin, A., 2020. An evaluation of the benefits of mobile fare payment technologyfrom the user and operator perspectives. Transport Policy 93, 54–66. URL: https://www.sciencedirect.com/science/article/pii/S0967070X19304056, doi:https://doi.org/10.1016/j.tranpol.2020.04.015.

Carneiro, M., Ribeiro, L., Biderman, C., 2019. Expansión urbana y exclusión social: accesibilidad y mercado de trabajo en río de janeiro. RevistaEURE 45, 95–117. URL: https://doi.org/10.4067/S0250-71612019000300051, doi:10.4067/S0250-71612019000300051.

Cortés, Y., 2021. Spatial accessibility to local public services in an unequal place: Santiago, chile. Sustainability 13, 442. URL: https://doi.org/10.3390/su13020442, doi:10.3390/su13020442.

Cui, B., Boisjoly, G., El-Geneidy, A., Levinson, D., 2019. Accessibility and the journey to work through the lens of equity. Journal of Transport
Geography 74, 269–277. doi:10.1016/j.jtrangeo.2018.12.003.

Dirección de Transporte Público Metropolitano, 2024. Informe de gestión 2024. URL: https://www.dtpr.gob.cl.

Directorio de Transporte Público Metropolitano (DTPM), 2024. Red movilidad: viajes liberados gracias al Dale QR!aumentaron en 33% durante el primer semestre. https://www.dtpm.cl/index.php/noticias-2/noticias-dtpm/1165-red-movilidad-viajes-liberados-gracias-al-dale-qr-aumentaron-en-33-durante-el-primer-semestre. Notaoficial con cifras de beneficio Dale QR!

Directorio de Transporte Público Metropolitano (DTPM), 2025. Tarjeta bip! https://www.dtpm.cl/index.php/114-tarjeta-bip. Medio
de pago oficial; inicio en 2007

References

Dodel, M., Hernandez, D., 2025. Smarter but more unequal transport? how socioeconomic and digital inequalities hinder adoption of mobility apps in the global south. Travel Behaviour and Society 38, 100911. URL: https://www.sciencedirect.com/science/article/pii/S2214367X24001741, doi:https://doi.org/10.1016/j.tbs.2024.100911.

Durand, A., Zijlstra, T., Hamersma, M., Hoen, A., van Oort, N., Hoogendoorn-Lanser, S., Hoogendoorn, S., 2023. “who can i ask for help?”:Mechanisms behind digital inequality in public transport. Cities 137, 104335. URL: https://www.sciencedirect.com/science/article/pii/S0264275123001476, doi:https://doi.org/10.1016/j.cities.2023.104335.

Ellison, R.B., Ellison, A.B., Greaves, S.P., Sampaio, B., 2017. Electronic ticketing systems as a mechanism for travel behaviour change? evidencefrom sydney’s opal card. Transportation Research Part A: Policy and Practice 99, 80–93. URL: https://www.sciencedirect.com/science/article/pii/S0965856416304748, doi:https://doi.org/10.1016/j.tra.2017.03.004.

Garau, C., Desogus, G., Barabino, B., Coni, M., 2022. Accessibility and public transport mobility for a smart(er) island: Evidence from sardinia (italy). Sustainable Cities and Society 87, 104145. doi:10.1016/j.scs.2022.104145.

Geurs, K.T., van Wee, B., 2004. Accessibility evaluation of land-use and transport strategies: review and research directions. Journal of TransportGeography 12, 127–140. URL: https://doi.org/10.1016/j.jtrangeo.2003.10.005, doi:10.1016/j.jtrangeo.2003.10.005.

Golub, A., Martens, K., 2014. Using principles of justice to assess the modal equity of regional transportation plans. Journal of Transport Geography 41, 10–20. URL: https://www.sciencedirect.com/science/article/pii/S0966692314001628, doi:https://doi.org/10.1016/j.jtrangeo.2014.07.014.

Gschwender, A., Munizaga, M.A., Simonetti, C., 2016. Using smart card and gps data for policy and planning: The case of transantiago.Research in Transportation Economics URL: https://doi.org/10.1016/j.retrec.2016.05.004, doi:10.1016/j.retrec.2016.06.004. penetración de tarjeta y cobertura GPS/AVL.

Handy, S., Niemeier, D.A., 1997. Measuring accessibility: an exploration of issues and alternatives. Environment and Planning A 29, 1175–1194.doi:10.1068/a291175.

Hansen, W.G., 1959. How accessibility shapes land use. Journal of the American Institute of Planners 25, 73–76. URL: https://doi.org/10.1080/01944365908978307, doi:10.1080/01944365908978307.

Henriquez-Jara, B., Arriagada, J., Tirachini, A., 2025. Impact of real-time information on passenger satisfaction across varying public transportquality levels in 13 chilean cities. Transportation Research Part A: Policy and Practice 200, 104622. URL: https://www.sciencedirect.com/science/article/pii/S0965856425002502, doi:https://doi.org/10.1016/j.tra.2025.104622.

Hernandez, D., Hansz, M., Massobrio, R., 2020. Job accessibility through public transport and unemployment in latin america: The case of montevideo (uruguay). Journal of Transport Geography 85, 102742. doi:10.1016/j.jtrangeo.2020.102742.

Iglesias, V., Giraldez, F., Tiznado-Aitken, I., Muñoz, J.C., 2019. How uneven is the urban mobility playing field? inequalities among socioeconomic groups in santiago de chile. Transportation Research Record 2673, 59–70. doi:10.1177/0361198119849588.

Instituto Nacional de Estadísticas de Chile, 2018. Censo de población y vivienda 2017. https://www.ine.gob.cl/estadisticas/sociales/ censos-de-poblacion-y-vivienda/censo-de-poblacion-y-vivienda. Base de datos oficial de variables sociodemográficas.

Islam, M.F., Fonzone, A., 2021. Bus passenger path choices after consulting ubiquitous real-time information. Travel Behaviour and Society 23,226–239. URL: https://www.sciencedirect.com/science/article/pii/S2214367X21000016, doi:https://doi.org/10.1016/j.tbs.2021.01.001.

References

Li, L., Shalaby, A., 2024. Navigating the transit network: Understanding riders' information seeking behavior using trip planning data.Transportation Research Part A: Policy and Practice 185, 104096. URL: https://www.sciencedirect.com/science/article/pii/S0965856424001447, doi:https://doi.org/10.1016/j.tra.2024.104096.

Litman, T., 2024. Evaluating accessibility for transport planning. Victoria Transport Policy Institute. Disponible en: https://www.vtpi.org/access.pdf.

Lucas, K., 2012. Transport and social exclusion: Where are we now? Transport Policy 20, 105–113. URL: https://doi.org/10.1016/j.tranpol.2012.01.013, doi:10.1016/j.tranpol.2012.01.013.

Martens, K., Golub, A., Robinson, G., 2012. A justice-theoretic approach to the distribution of transportation benefits: Implications for transportationplanning practice in the united states. Transportation Research Part A: Policy and Practice 46, 684–695. URL: https://doi.org/10.1016/j.tra.2012.01.004, doi:10.1016/j.tra.2012.01.004.

Ministerio de Educación de Chile, 2025. Directorio de establecimientos educacionales. https://datosabiertos.mineduc.cl/directorio-de-establecimientos-educacionales/. Ministerio de Educación, Gobierno de Chile. Accessed October 2025.

Ministerio de Transportes y Telecomunicaciones / Red Movilidad, 2025. Red movilidad — aplicación oficial (google play). https://play.google.com/store/apps/details?id=com.sonda.wiu. Descripción de funcionalidades, planificación y ETAs.

Mogaji, E., Nguyen, N.P., 2024. Evaluating the emergence of contactless digital payment technology for transportation. Technological Forecastingand Social Change 203, 123378. URL: https://www.sciencedirect.com/science/article/pii/S0040162524001744, doi:https://doi.org/10.1016/j.techfore.2024.123378.

Mohri, S.S., Mortazavi, S., Nassir, N., 2021. A clustering method for measuring accessibility and equity in public transportation service: Case study of melbourne. Sustainable Cities and Society 74, 103241. doi:10.1016/j.scs.2021.103241.

Munizaga, M.A., Palma, C., 2012. Estimation of a disaggregate multimodal public transport origin–destination matrix from passive smartcard data from santiago, chile. Transportation Research Part C: Emerging Technologies 24, 9–18. URL: https://doi.org/10.1016/j.trc.2012.01.007, doi:10.1016/j.trc.2012.01.007.

Nguyen, S., Pallottino, S., 1988. Equilibrium traffic assignment for large scale transit networks. European journal of operational research 37,176–186.

Núñez Sepúlveda, C., 2015. Calculation of Service Quality Indicators for the Santiago Public Transport System Using Passive Data. Master's thesis. Universidad de Chile. URL: https://repositorio.uchile.cl/handle/2250/133536.

Ojeda Fontecilla, M.A., 2023. Estimación de inequidad social en la accesibilidad de transporte a centros de atención de salud en Santiago. Master's thesis. Universidad de Chile, Facultad de Ciencias Físicas y Matemáticas, Departamento de Ingeniería Industrial. Santiago, Chile. URL: https://repositorio.uchile.cl/handle/2250/194875. memoria para optar al título de Ingeniera Civil Industrial.

Pereira, R.H.M., Schwanen, T., Banister, D., 2017. Distributive justice and equity in transportation. Transport Reviews 37, 170–191. URL: https://doi.org/10.1080/01441647.2016.1257660, doi:10.1080/01441647.2016.1257660.

Red Movilidad, 2025a. App red movilidad: funciones y pago con qr. https://www.red.cl/acerca-de-red/app-red/. Información oficial sobre ETA, recorridos y pago QR.

Red Movilidad, 2025b. Sistema red movilidad suma un nuevo medio de pago con relojes inteligentes. https://www.red.cl/red-comunica/sistema-red-movilidad-suma-un-nuevo-medio-de-pago-con-relojes-inteligentes/. Más de 4 millones de enrolados al pago con QR; validación con wearables.

References

Secretaría de Planificación de Transporte (SECTRA), 2018. Encuesta origen destino del gran santiago 2012, actualizada al año 2017. https://www.sectra.gob.cl/encuestas_movilidad/encuestas_movilidad.htm. Base de datos de movilidad y variables sociodemográficas.

Servicio de Impuestos Internos de Chile, n.d. Consulta de catastro y roles de avalúo fiscal. https://www4.sii.cl/sismunInternet6/?caller=DETALLE_CAT_Y_ROL_COBRO. Plataforma de consulta de información catastral y uso de suelo.

Shen, Q., 1998. Location characteristics of inner-city neighborhoods and employment accessibility of low-wage workers. Environment and Planning B: Planning and Design 25, 345–365. URL: https://www.researchgate.net/publication/23541082_Location_Characteristics_of_Inner-City_Neighborhoods_and_Employment_Accessibility_of_Low-Wage_Workers, doi:10.1068/b250345.

Soukhov, A., Paez, A., Higgins, C.D., Mohamed, M., 2023. Introducing spatial availability, a singly-constrained measure of competitive accessibility. PLOS ONE 18, e0278468. URL: https://doi.org/10.1371/journal.pone.0278468, doi:10.1371/journal.pone.0278468.

Tiznado-Aitken, I., Muñoz, J.C., Hurtubia, R., 2021. Public transport accessibility accounting for level of service and competition for urban opportunities: An equity analysis for education in santiago de chile. Journal of Transport Geography 90, 102919. URL: https://doi.org/10.1016/j.jtrangeo.2020.102919, doi:10.1016/j.jtrangeo.2020.102919.

Wani, S.A., Pani, A., Mohan, R., Bhowmik, B., 2025. Digital payment adoption in public transportation: Mediating role of mode choice segments in developing cities. Transportation Research Part A: Policy and Practice 191, 104319. URL: https://www.sciencedirect.com/science/article/pii/S0965856424003677, doi:https://doi.org/10.1016/j.tra.2024.104319.

Xi, H., Nelson, J.D., Mulley, C., Hensher, D.A., Ho, C.Q., Balbontin, C., 2025. Barriers towards enhancing mobility through integrated mobility services in a regional and rural context: insights from suppliers and organisers. Transport Policy 171, 282–295. URL: https://www.sciencedirect.com/science/article/pii/S0967070X25002379, doi:https://doi.org/10.1016/j.tranpol.2025.06.012.

Yang, L., et al., 2019. Evaluating the urban land use plan with transit accessibility. Sustainable cities and society 45, 474–485.

Yigitcanlar, T., Downie, A.T., Mathews, S., Fatima, S., MacPherson, J., Behara, K.N., Paz, A., 2024. Digital technologies of transportation-related communication: Review and the state-of-the-art. Transportation Research Interdisciplinary Perspectives 23, 100987. URL: https://www.sciencedirect.com/science/article/pii/S2590198223002348, doi:https://doi.org/10.1016/j.trip.2023.100987.

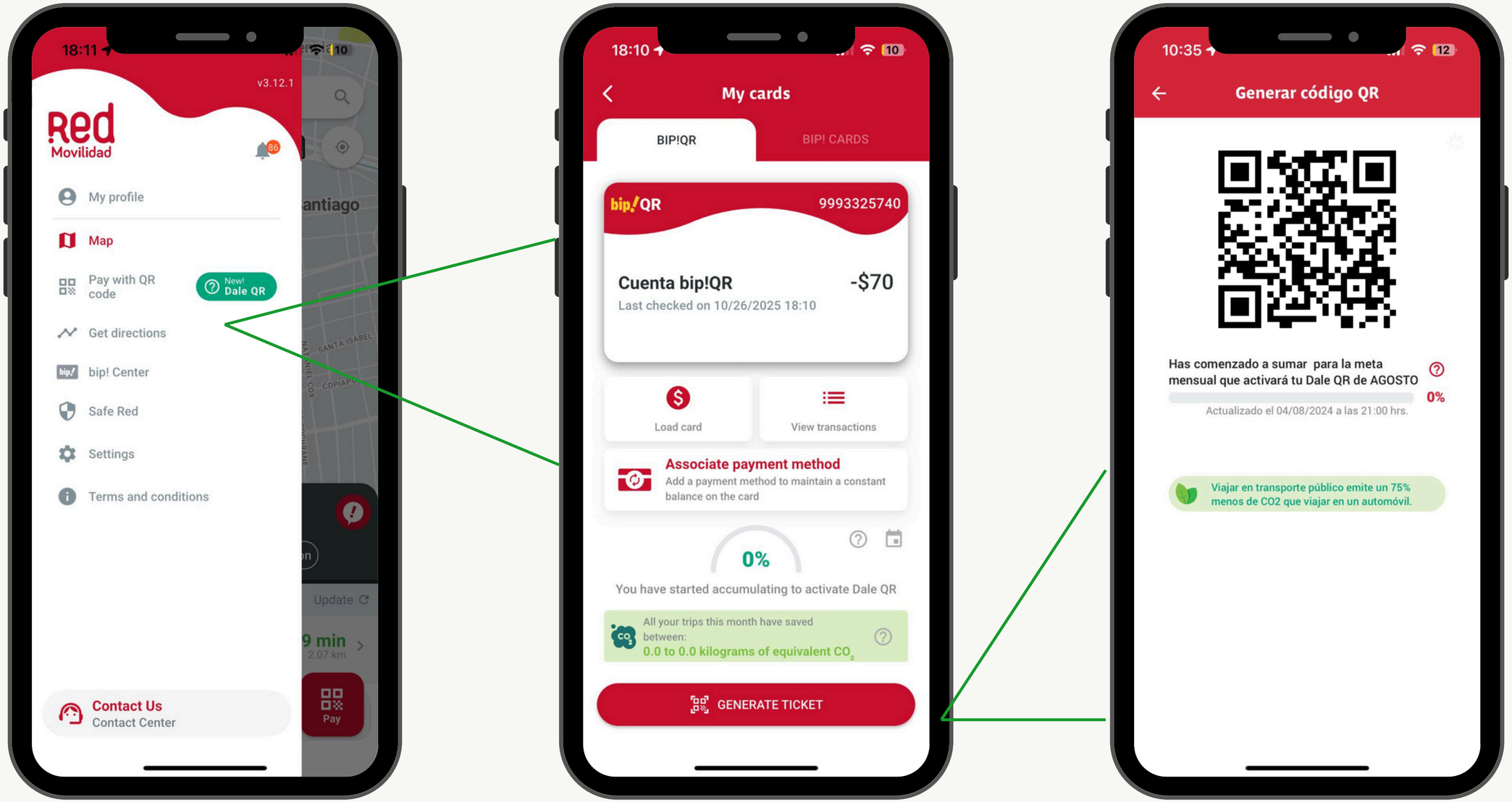
Yigitcanlar, T., Kamruzzaman, M., Foth, M., Sabatini-Marques, J., da Costa, E., Ioppolo, G., 2019. Can cities become smart without being
sustainable? a systematic review of the literature. Sustainable Cities and Society 45, 348–365. doi:10.1016/j.scs.2018.11.033.

Zhang, A., Xia, C., Chu, J., Lin, J., Li, W., Wu, J., 2019. Portraying urban landscape: A quantitative analysis system applied in fifteen metropolises in china. Sustainable Cities and Society 46, 101396

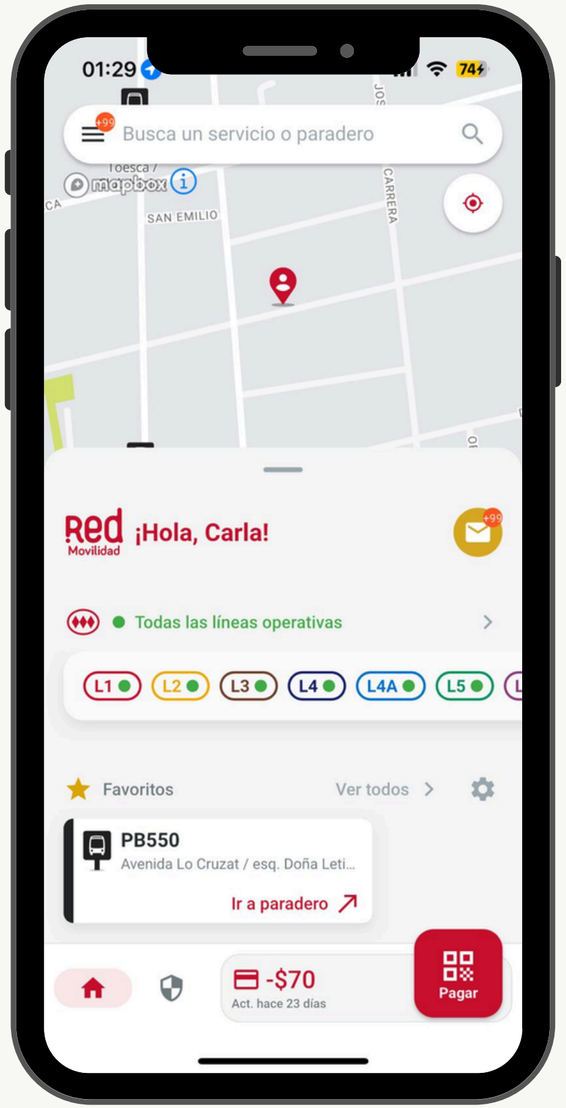
Appendix

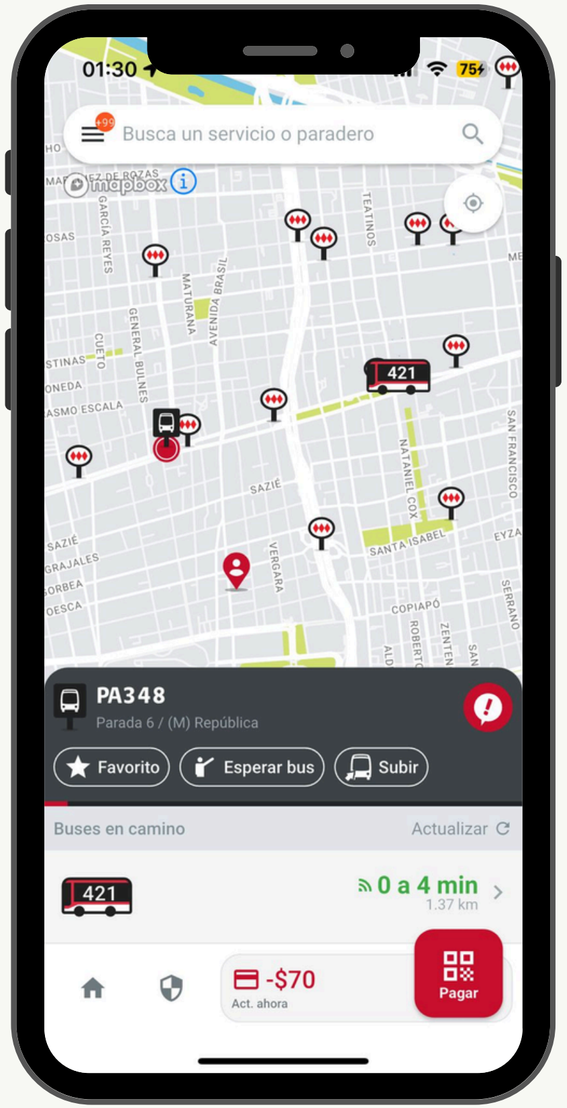
Backup slides.

APPENDIX A1


18:11
v3.12.1
Red Movilidad
My profile
Map
Pay with QR code
New! Dale QR
Get directions
bip! Center
Safe Red
Settings
Terms and conditions
Contact Us
Contact Center
Update
9 min
2.07 km
Pay
18:10
My cards
BIP!QR
BIP! CARDS
bip!QR
9993325740
Cuenta bip!QR
-$70
Last checked on 10/26/2025 18:10
Load card
View transactions
Associate payment method
Add a payment method to maintain a constant balance on the card
0%
You have started accumulating to activate Dale QR
All your trips this month have saved between:
0.0 to 0.0 kilograms of equivalent CO2
GENERATE TICKET
10:35
Generar código QR
Has comenzado a sumar para la meta mensual que activará tu Dale QR de AGOSTO
0%
Actualizado el 04/08/2024 a las 21:00 hrs.
Viajar en transporte público emite un 75% menos de CO2 que viajar en un automóvil.

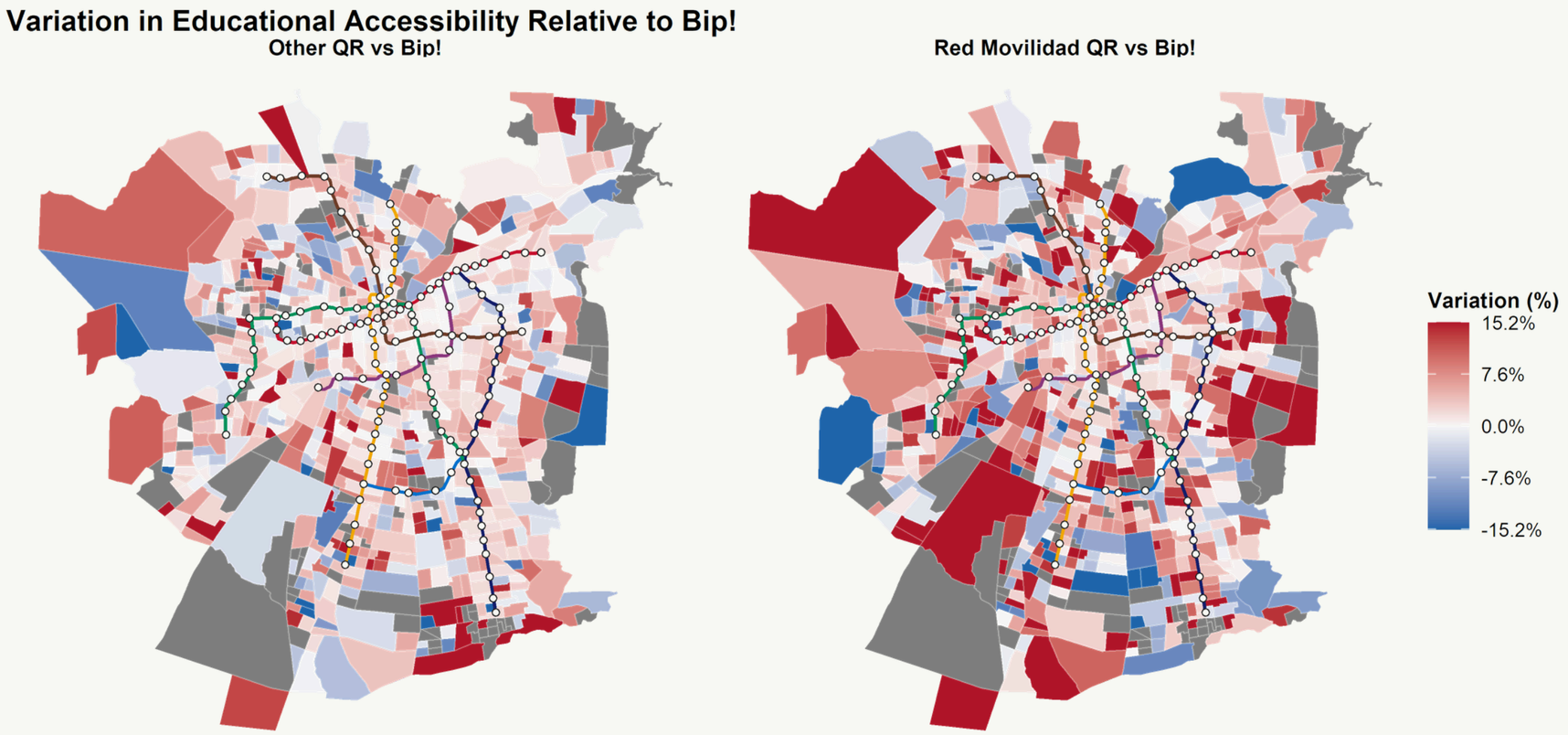
APPENDIX A1


01:29
Busca un servicio o paradero
SAN EMILIO
CARRERA
Red Movilidad ¡Hola, Carla!
Todas las líneas operativas
L1 L2 L3 L4 L4A L5
Favoritos
Ver todos
PB550
Avenida Lo Cruzat / esq. Doña Leti...
Ir a paradero
-$70
Act. hace 23 días
Pagar


01:30
Busca un servicio o paradero
421
PA348
Parada 6 / (M) República
Favorito
Esperar bus
Subir
Buses en camino
Actualizar
421
0 a 4 min
1.37 km
-$70
Act. ahora
Pagar


01:31
Conoce los desvíos de hoy en Al...
Conoce los desvíos de hoy en Alameda
De Red
Mensaje
31 de diciembre, 9:00
⚠️ Atención:
Planifica tu viaje si te desplazas por Alameda durante esta jornada, servicios RED tendrán desvíos por preparativos y evento de celebración de Año Nuevo en Torre Entel.
🚔 Desde las 11 AM. habrá cortes en Alameda en su calzada norte desde Miraflores.
🚔 A partir de las 14 hrs. se suman desvíos hacia el oriente desde Av. España.
📌 Y desde las 15 hrs. y hasta la finalización del evento, servicios tendrán desvíos en eje Alameda-Providencia entre Vicuña Mackenna y Exposición.
📲 Usa la APP Red Movilidad para conocer las rutas, en la opción alertas de cada parada.
📌 Recuerda que si tienes dudas, puedes llamarnos al 📲 600 730 00 73 / 📞 800 73 00 73.
¿Te ayudó esta información? ¡Deja tu valoración AQUÍ!
-$70
Act. hace un minuto
Pagar

Digital gains are not distributed evenly across the city.



A larger relative gain can occur because baseline accessibility in those areas is low. When the starting point is low, even a small absolute change can look large in relative terms.

APPENDIX A2

Data construction flow.

1. Temporal selection
Weekday morning-peak trips (5:00–9:00) from April 2024 and April 2025.
Initial dataset: 30,842,561 trips

↓

2. Trip cleaning
Removal of incomplete records, identical boarding and alighting stops, inconsistent timestamps, and other invalid observations.
Remaining dataset: 29,052,692 trips

↓

3. Travel-time and spatial matching
Calculation of travel-time components; assignment of origins and destinations to analysis zones and spatial attributes.

↓

4. OD matrix and opportunities
Aggregation by OD pair, year, and payment method; matching with educational and employment opportunities.
Final dataset: 119,748 OD pairs

Kept as backup because the main talk only needs the data blocks and sources.

APPENDIX A3

Estimated payment shares in Red Movilidad trips.

Payment method	2024	2025	Description
Smartcard bip!	85.9%	81.6%	Traditional contactless card
External QR apps	11.1%	14.6%	Financial or third-party applications
QR Red app	3.0%	3.8%	Official app payment interface

APPENDIX A4

Spatial distribution of QR trips by origin macrozone.

Macrozone	QR Red	Other QR
Central Area	13.5%	17.0%
North	5.4%	9.8%
East	41.7%	18.8%
West	13.1%	20.7%
South	9.5%	13.7%
Southeast	16.8%	20.0%
Total	100.0%	100.0%

APPENDIX A6

Limitations and identification.

Observational design

The models estimate conditional associations, not causal effects.

Proxy

QR Red is a proxy for access to the official app ecosystem; actual app consultation is not observed.

Spatial scale

Zone-level indicators may hide within-zone heterogeneity and opportunity quality.

Temporal scope

The analysis covers April 2024 and April 2025, weekday AM peak trips.

APPENDIX A7

Generalized travel time

$$T_{ij}^{gen,n,t} = \beta_{w1} t_{wait,ij}^{n,t} + \beta_{w2} t_{twait,ij}^{n,t} + \beta_{walk} t_{walk,ij}^{n,t} + \beta_{veh} t_{veh,ij}^{n,t} + \beta_{transf} N_{transf,ij}^{n,t} \quad (1)$$

where i is the origin zone, j is the destination zone, n is the payment method, and t is the year. The coefficients used in this calculation, shown in Table 4,are drawn from Arriagada et al. (2022), where in-vehicle time serves as the reference component with a weight of one.

Table 4
Components and coefficients used in the generalized travel time calculation.

Component	Symbol in Eq. (1)	Description	Coefficient	Value
Initial waiting time	t_{wait}	Average time before boarding the first vehicle	β_{w1}	1.9
Average transfer waiting time	t_{twait}	Average waiting between connecting services	β_{w2}	1.3
Average transfer walking time	t_{walk}	Walking between stops or stations	β_{walk}	3.19
Number of transfers	N_{transf}	Service changes during the trip	β_{transf}	13.5
Average in-vehicle time	t_{veh}	Time spent inside bus or Metro	β_{veh}	1.0

APPENDIX A9

travel-time components

Table 7
Average observed and generalized travel-time components (in minutes) by payment method and year.

Component	Red Movilidad QR		Smart card Bip!		Other QR	
	2024	2025	2024	2025	2024	2025
Observed travel time						
Total observed travel time	40.99	41.85	41.09	42.10	41.03	42.15
Walking time	1.30	1.27	1.32	1.31	1.27	1.25
Transfer waiting time	0.97	1.01	1.00	1.01	0.99	0.97
Initial waiting time	8.96	9.62	9.04	9.77	8.91	9.74
In-vehicle time	29.76	29.95	29.73	29.99	29.85	30.18
Generalized travel time						
Total generalized travel time	56.91	58.14	57.19	58.61	56.70	58.17
Weighted walking time	6.36	6.23	6.48	6.45	6.24	6.13
Weighted transfer waiting time	1.26	1.31	1.30	1.31	1.29	1.26
Weighted initial waiting time	13.94	15.00	14.10	15.25	13.90	15.20
In-vehicle time	29.76	29.95	29.73	29.99	29.85	30.18
Transfer penalty	5.59	5.65	5.58	5.61	5.42	5.40

Note: Generalized components apply the coefficients reported in Table 4. The transfer penalty corresponds to the weighted number of transfers.

The generalized-time results help us understand the mechanism more clearly.

41-42

minutes of observed travel time

→

57-59

minutes of generalized travel time

Interpretation

Real-time information matters most in uncertain parts of the trip: waiting, transfers, and route coordination.

Area	Education loss	Job loss	Pattern
Central	6.3%	8.1%	Lower penalty
Southeast	14.0%	19.9%	Higher penalty

APPENDIX A8

Independent variables in the models

Table 5
Independent variables included in the econometric models.

Variable	Description	Unit
Red Movilidad QR share	Trips originating in the zone and paid using QR through the official Red Movilidad app.	% of trips
Other QR share	Trips originating in the zone and paid using QR through other applications.	% of trips
Female population	Female residents in the zone.	% of population
Migrant population	Residents born outside Chile.	% of population
Elderly population	Residents aged 65 years or older.	% of population
Low-income households	Households classified in the lower income deciles.	% of households
Vehicles per household	Average number of private vehicles available per household.	Vehicles/household
Employment rate	Employed residents relative to the working-age population.	%
Student share	Residents enrolled in education.	% of population
Unemployment rate	Unemployed residents relative to the labor force.	%
Driver's license holders	Residents holding a driver's license.	% of population
Number of trips	Trips originating in the zone during the study period.	Trips
Average number of stages	Mean number of public transport stages per trip originating in the zone.	Stages/trip
Number of services	Distinct public transport services available in the zone.	Services
Stop density	Public transport stops per square kilometer.	Stops/km^2
Distance to Metro	Distance from the zone centroid to the nearest Metro station.	km
Nearby Metro stations	Metro stations located in the corresponding macrozone.	Stations

Note: All variables are measured at the origin-zone level unless otherwise indicated.