Chapter 7

Conclusion

Travel demand and transport infrastructure are highly correlated. Travel demand is shaped by infrastructure investments. At the same time, investments in transport infrastructure are made to address (future) travel demand. The correlation, however, does not explain their causal relationship. When observations over different points of time are available, predictions on causal relationships can be analysed through time-series analyses. A typical question that arises within time-series analyses is whether or not one variable can help forecast another. Granger causality tests infer the direction of causality by testing whether lagged information on a time-series variable X provides significant information about another variable Y. Such tests have been conducted in the context of transport infrastructure and economic growth, and land use and transport. This research extended that by examining the co-evolution of public transport network infrastructure and ridership in the Greater Sydney region.

The scope of this research included collecting and processing Sydney's historic public transport network and ridership data, modelling the co-evolution of public transport network and ridership measures, and disentangling inter-modal dynamics between public transport modes. A review of the findings, a discussion on the contributions and implications, and a note on the limitations and future directions of the research are presented in the following sections.

7.1 A review of findings

In chapter 2, I reviewed and analysed empirical causal studies and co-evolutionary models conducted with longitudinal data in the field of transport. Granger causality tests were the most popular method of investigation. Studies investigating causality between network investments and travel demand were limited. Investigations on transport infrastructure were limited to rail and highway networks. Causal studies investigating public transport ridership and accessibility were non-existent.

In chapter 3, I outlined the process of generating public transport networks for the Greater Sydney region for a period spanning from 1855 to 2015. The process involved digitizing historic bus networks from archived information on route and timetable changes, and converting the geo-referenced routes and timetables into General Transit Feed Specification (GTFS) files for each year. These were combined with similarly generated files for train and tram and were used to measure public transport access across the study period. The GTFS generation method was validated by comparing public transport access resulting from the generated GTFS for 2015 with that published by the state transport authority. A difference in average access of less than 2% was observed across the region.

The region's historic public transport ridership data was discussed in chapter 4. Three types of ridership data were available – aggregate annual ridership by mode, disaggregate (train) station ridership, and public transport mode share. Multiple sources were explored to prepare a time series of aggregate annual journeys by all public transport modes from 1876 onward. Station ridership panels were generated for three time periods – 1877 to 1940, 1976 to 1990, and 2001 to 2012. This involved ticket to journey conversions and interpolations for some missing years. For census years starting 1991, public transport mode shares were available from the census. However, their geographical boundaries were inconsistent across years and had to be standardised. I spatially interpolated shares given for travel zones to smaller mesh blocks using Triangular Integrated Network interpolation.

In chapter 5, I presented the causal models estimated between aggregate public transport ridership and access, station ridership and access, and mesh block public transport shares and access. I found a mutual feedback between public transport access and demand as expected in all models, and the causality was more evident in the disaggregate models. A stronger causal relationship was observed between ridership and access to jobs than with access to population in cases where employment details were available.

Finally in chapter 6, I explored complementarity among public transport modes by comparing and contrasting access provided in cases formed by different combinations of the modes – train, tram and bus – across the time period. I found the sub-additive interactions between the modes. Benefits of transferring between modes were significant only at higher travel time thresholds (30 minutes and higher) and varied both temporally and spatially.

7.2 Contributions and implications

There are three main contributions of this research.

1. Historic public transport network, access, and ridership data-series generated for the Greater Sydney region since 1855.
2. Historic causal investigation of public transport access and ridership.
3. Measurement of modal complementarity.

The implications of each main contribution are discussed in turn:

Historic public transport network, access, and ridership data-series generated for the Greater Sydney region since 1855. An appreciation and understanding of history is important to plan for the future. The time-series data generated as part of this research form a valuable resource on Sydney's public transport history. Since Sydney's first train service in 1855, both public transport network access and ridership increased steadily until World War II (WWII). Post-WWII, the popularity of automobiles led to a decline in both public transport supply and demand. It was only in the 1980s and 90s that a revival of public transport began, due perhaps to high congestion levels caused by a population growing faster than the road network, and increasing awareness of the adverse effects of high automobile travel. Although Sydney's population today is multiples of what it was during WWII, public transport ridership in 2014 was lower than what it was in 1945 and access in 2014 was comparable to the values in 1945. With increasing pressure on Australia to reduce emissions and fossil-fuel dependence, policies that increased public transport investments and patronage would play a major role in reaching carbon and emission-reduction targets. This dissertation's historic public transport ridership and access time-series would provide a valuable measuring scale to evaluate and track such policies.

While the generated data is Sydney-specific, the method adopted in processing and validating the data can be transferred for applications in other regions. Applications of such longitudinal data are numerous both in research and practice. In addition to investigating causal directions, they can be used in building evolutionary transport and land use models. Changes in network structure characteristics can be investigated and extended to explore network structure attributes (density, circuity, etc.) that are most correlated with demand. Ex-post analyses can be conducted to investigate the impacts of network and service variations on ridership and used to inform future planning and design of public transport services. When coupled with spatially disaggregated information on income levels, one can also conduct ex-post analyses on the impacts of infrastructure investments on different income groups as done for Paris in Viguié et al. (2023). Further when detailed street network evolution and public transport stop locations are available, the evolution of social exclusion can be investigated by measuring walking accessibility to public transport stops as in Ribeiro et al. (2021).

Historic causal investigation of public transport access and ridership. Such an exercise has not been conducted previously. While access has been known and observed to influence ridership (H. Wu et al., 2021), this is the first longitudinal investigation into their causal relationship. The confirmation of a mutual feedback between public transport access and demand can be used to strengthen the case for using access as a planning measure. It can support advocacy for active investment in public transport supply as demand will evidently follow.

Growing countries like Australia with increasing immigrant population have a unique opportunity to nudge travel behaviour away from private vehicles by heavily investing in public transport infrastructure alongside new suburban developments. In New South Wales, public transport services are provided by the state government based on observed and forecast demand. Real estate development, on the other hand, is regulated by local councils, though constrained by the availability of public infrastructure like water and sewer provided more regionally. Consequently, there is often a lag between when new developments are commissioned and when public transport services reach them. So residents move in before adequate public transport options are available and are forced to rely on private vehicles. A solution as evidenced by the findings of this research is to remove the lag between land development and public transport infrastructure provision. For this, state and local governments would have to work together with land developers to ensure concurrent public transport network provision as part of development applications just as they mandate minimum parking spaces for cars. The mandates would be best stipulated in terms of cumulative-opportunity-based access measures to different types of destinations, for instance, X number of (and type of) schools and shopping opportunities to be reached within 15 minutes, Y number and type of employment opportunities to be reached within 30 minutes, etc. When the size of the developments warrant public transport hubs, adopting a land value capture model would further incentivise developers' engagement in the process.

While the modelling undertaken in this research is Sydney-specific, and future research is required to know the extent to which the parameters are spatially or temporally transferable, the logic is transferable and should hold true for any historic city. The dataset and method also lay the ground work for a co-evolutionary investigation of public transport investments and land value to further evaluate investments in infrastructure.

Measurement of modal complementarity. Comparing and contrasting access by various public transport modal combinations revealed a highly sub-additive nature of Sydney's public transport modes. This is perhaps because of a lack of integration between entities responsible for planning the different modal networks. Although the state government – today's Transport for New South Wales (TfNSW) – is responsible for providing all public transport services, Sydney Trains, Sydney Metro, and Sydney Ferries are separate entities within TfNSW, and bus services are contracted out to various private operators. In such a setting, integration among the modal networks and services is difficult but important and can be facilitated through modal complementarity evaluations such as the one presented in this research.

Comparison of access by modal combinations can be used as a planning tool to ensure equitable supply and to investigate transfer benefits and penalties. Combining this analysis with ridership will provide insights into how ridership is affected by modal complementarity and competition.

7.3 Limitations and future directions

7.3.1 Evolutionary modelling

My research was a first step towards understanding the causal relationship between network investments and travel demand. Future research should take the understanding of the mutual feedback and the database generated to the next steps of integration with travel demand models to build evolutionary models. Causal models specified as structural equations aided by path diagrams as proposed by Pearl (2009) could be worth exploring for this integration.

7.3.2 Historic public transport network database

The historic public transport network database generated is limited, naturally, by the extent and nature of data available. Details of express and inter-city train services that also served suburban stations were not available historically. This prevented the integration of my database with the published network information available from 2015 onward. Consequently, the causal analysis could not be extended to the more recent years.

Detailed information on ferry routes and services would add to the completeness of the database. The historic bus networks could be improved with historic information on stop locations and street network. I had to assume stop locations for streets where no stops exist in the 2019 GTFS. Stop locations were also held constant across the study period. Access computations are significantly influenced by stop locations. Without historic stop location data, my analysis does not capture the differences in access caused due to changes in stop spacing and other stop-related attributes. The street network was also held constant while generating bus routes as street opening and closing information was not readily available. When this becomes available, the networks can be updated to capture the influence of street-level changes.

Public transport access was computed as cumulative opportunities reached, and population was primarily considered as historic information on other opportunities like jobs, shops, schools, etc. was limited. A more holistic measure of access would provide deeper insights.

7.3.3 Spatially disaggregate ridership data

Aggregate public transport ridership was derived by combining journeys reported individually for train, tram, and bus. This might overestimate ridership as a result of inter-modal transfers being accounted for more than once. Moreover, the number of journeys reported were estimated from ticket sales using multipliers. The estimations of multipliers and their implications on data comparability across the study period are unclear.

Train station ridership was not available as a continuous series across the study period. Regional journeys originating from suburban stations were included in the earlier period (1877 to 1940), and were excluded in the data for the more recent periods (1976 to 1990 and 2001 to 2012). Even for the periods with data, assumptions and interpolations had to be made to overcome inconsistencies and incompleteness in the reported information.

Historic ridership data was unavailable for buses and trams at a spatially disaggregated scale. Further insights into the causal relationships could be explored with such data on all modes.

7.3.4 Exogenous factors influencing supply and demand

My research investigated the endogenous influence of public transport investments on ridership and vice-versa. Not all exogenous factors influencing the two could be considered. GDP was used as an employment-level and recession tracker, and population was used as a control factor for demographic changes. Investments in, and demand for, other transport modes, congestion, crowding, political directives and other policy drivers would be interesting factors to consider when such information is available.

7.3.5 Multi-modal interactions

I explored modal interactions among public transport modes. Extending this to private automobile and active modes would be an interesting research direction. Availability of information on historic street network changes would be crucial for this analysis.

Similarly when historic ridership data by mode can be availed, coupling access and demand with a modal complementarity analysis would be a valuable research exercise. Which modes are complementary to each other in terms of ridership? Increased access to which mode results in the highest ridership levels overall? These are some of the questions such an investigation can answer.

My access calculations consider only travel time. Historically, transfers between modes were charged a fee. This additional cost of transfers was not considered in my analysis. Consideration of fares as well as time in calculating access would address this shortcoming. However, this calls for additional data on historical fares and incomes.

Appendices

Appendix A

A.1 Model estimates: Aggregate public transport ridership and access

Table A.1 documents the results from causal models estimated on aggregate public transport ridership and 30- and 60-minute net public transport access to population. Similar results for regressions estimated for change in the dependent variables (as specified in Equation 5.4 and Equation 5.5) are presented in Table A.2.

Table A.1: Aggregate public transport ridership, R_t, and 30- and 60-minute net access to population, $A_{30p,t}$ and $A_{60p,t}$: 1876 to 2014 ($N = 137$)

	Coeff.	S.E.	p	R^2	Coeff.	S.E.	p	R^2
	Dependent variable: R_t				Dependent variable: $A_{30p,t}$			
Lagged ridership, R_{t-2}	9.67E-01	1.62E-02	0.000					
Lagged change in 30-minute net access, $\Delta A_{30p,(t-1)-(t-2)}$	2.05E-03	1.50E-03	0.174					
Lagged change in catchment population, $\Delta P_{(t-1)-(t-2)}$	-1.08E-04	1.49E-04	0.471	0.978				
Lagged change in GDP-per-capita, $\Delta G_{(t-1)-(t-2)}$	1.72E-02	5.94E-03	0.005					
Constant	2.04E+01	6.67E+00	0.003					
Lagged 30-minute net access, $A_{30p,t-2}$					9.02E-01	1.62E-02	0.000	
Lagged change in ridership, $R_{t-(t-1)}$					5.78E+01	1.37E+01	0.000	
Lagged change in catchment population, $\Delta P_{t-(t-1)}$					2.05E-02	1.11E-02	0.067	0.964
Lagged change in GDP-per-capita, $\Delta G_{t-(t-1)}$					-2.04E+00	5.35E-01	0.000	
Constant					4.66E+03	8.40E+02	0.000	
	Dependent variable: R_t				Dependent variable: $A_{60p,t}$			
Lagged ridership, R_{t-2}	9.70E-01	1.54E-02	0.000					
Lagged change in 60-minute net access, $\Delta A_{60p,(t-1)-(t-2)}$	8.76E-04	4.11E-04	0.035					
Lagged change in catchment population, $\Delta P_{(t-1)-(t-2)}$	-1.68E-04	1.51E-04	0.268	0.978				
Lagged change in GDP-per-capita, $\Delta G_{(t-1)-(t-2)}$	1.72E-02	5.88E-03	0.004					
Constant	1.93E+01	6.54E+00	0.004					
Lagged 60-minute net access, $A_{60p,t-2}$					9.46E-01	1.02E-02	0.000	
Lagged change in ridership, $R_{t-(t-1)}$					1.41E+02	5.05E+01	0.006	
Lagged change in catchment population, $\Delta P_{t-(t-1)}$					1.93E-01	4.27E-02	0.000	0.988
Lagged change in GDP-per-capita, $\Delta G_{t-(t-1)}$					-1.11E+00	1.95E+00	0.571	
Constant					1.28E+04	2.63E+03	0.000	

Catchment population indicates people living within 15-minute walking radius of public transport stations.

GDP per-capita values are inflation adjusted and available in 2011 USD from Bolt and Van Zanden, 2020.

Table A.2: Change in aggregate public transport ridership, $\Delta R_{t-(t-2)}$, and change in 30- and 60-minute net access to population, $\Delta A_{30,t-(t-2)}$ and $\Delta A_{60,t-(t-2)}$: 1876 to 2014 (N = 137)

	Coeff.	S.E.	p	R^2	Coeff.	S.E.	p	R^2
	Dependent variable: $\Delta R_{t-(t-2)}$				Dependent variable: $\Delta A_{30,t-(t-2)}$			
Lagged change in 30-minute net access, $\Delta A_{30,(t-1)-(t-2)}$	3.55E-03	1.32E-03	0.008	0.091				
Lagged change in catchment population, $\Delta P_{(t-1)-(t-2)}$	-2.52E-04	1.33E-04	0.060					
Lagged change in GDP-per-capita, $\Delta G_{(t-1)-(t-2)}$	1.46E-02	5.87E-03	0.014					
Constant	1.10E+01	4.85E+00	0.025					
Lagged change in ridership, $R_{t-(t-1)}$					4.50E+01	1.53E+01	0.004	0.084
Lagged change in catchment population, $\Delta P_{t-(t-1)}$					1.64E-02	1.25E-02	0.192	
Lagged change in GDP-per-capita, $\Delta G_{t-(t-1)}$					-1.21E-01	5.83E-01	0.040	
Constant					2.62E+02	4.81E+02	0.587	
	Dependent variable: $\Delta R_{t-(t-2)}$				Dependent variable: $\Delta A_{60,t-(t-2)}$			
Lagged change in 60-minute net access, $\Delta A_{60,(t-1)-(t-2)}$	1.22E-03	3.76E-04	0.002	0.111				
Lagged change in catchment population, $\Delta P_{(t-1)-(t-2)}$	-3.07E-04	1.35E-04	0.024					
Lagged change in GDP-per-capita, $\Delta G_{(t-1)-(t-2)}$	1.47E-02	5.80E-03	0.012					
Constant	1.05E+01	4.79E+00	0.030					
Lagged change in ridership, $R_{t-(t-1)}$					1.78E+02	5.48E+01	0.001	0.118
Lagged change in catchment population, $\Delta P_{t-(t-1)}$					1.25E-01	4.47E-02	0.006	
Lagged change in GDP-per-capita, $\Delta G_{t-(t-1)}$					-3.35E+00	2.09E+00	0.111	
Constant					1.61E+03	1.73E+03	0.354	

Catchment population indicates people living within 15-minute walking radius of public transport stations.

GDP per-capita values are inflation adjusted and available in 2011 USD from Bolt and Van Zanden, 2020.

A.2 Estimates of models with wars as dummy variables: Aggregate public transport ridership and access

Table A.3, Table A.4, and Table A.5 present the results from causal models estimated on aggregate public transport ridership and net 30-, 45-, and 60-minute public transport access to population with years under World War I (WWI) and World War II (WWII) included as dummy variables respectively.

Table A.3: Aggregate public transport ridership, R_t, and 30-, minute net access to population, $A_{30p,t}$, estimated with WWI and WWII as explanatory variables: 1876 to 2014 ($N = 137$)

	Coeff.	S.E.	p	R^2	Coeff.	S.E.	p	R^2
	Dependent variable: R_t				Dependent variable: $A_{30p,t}$			
Lagged ridership, R_{t-2}	9.37E-01	1.43E-02	0.000					
Lagged change in 30-minute net access, $\Delta A_{30p,(t-1)-(t-2)}$	4.68E-04	1.29E-03	0.717					
Lagged change in catchment population, $\Delta P_{(t-1)-(t-2)}$	8.28E-05	1.29E-04	0.522					
Lagged change in GDP-per-capita, $\Delta G_{(t-1)-(t-2)}$	1.76E-02	5.08E-03	0.001	0.984				
WWI	-4.52E+00	1.29E+01	0.726					
WWII	8.26E+01	1.13E+01	0.000					
Constant	2.38E+01	5.73E+00	0.000					
Lagged 30-minute net access, $A_{30p,t-2}$					9.03E-01	1.73E-02	0.000	
Lagged change in ridership, $R_{t-(t-1)}$					6.26E+01	1.52E+01	0.000	
Lagged change in catchment population, $\Delta P_{t-(t-1)}$					2.015E-02	1.11E-02	0.075	
Lagged change in GDP-per-capita, $\Delta G_{t-(t-1)}$					-2.03E+00	5.42E-01	0.000	0.964
WWI					4.27E+02	1.41E+03	0.762	
WWII					-9.00E+02	1.30E+03	0.491	
Constant					4.61E+03	8.59E+02	0.000	

Catchment population indicates people living within 15-minute walking radius of public transport stations.

GDP per-capita values are inflation adjusted and available in 2011 USD from Bolt and Van Zanden, 2020.

Table A.4: Aggregate public transport ridership, R_t, and 45-, minute net access to population, $A_{45p,t}$, estimated with WWI and WWII as explanatory variables: 1876 to 2014 ($N = 137$)

	Coeff.	S.E.	p	R^2	Coeff.	S.E.	p	R^2
	Dependent variable: R_t				Dependent variable: $A_{45p,t}$			
Lagged ridership, R_{t-2}	9.44E-01	1.42E-02	0.000					
Lagged change in 45-minute net access, $\Delta A_{45p,(t-1)-(t-2)}$	7.27E-04	5.77E-04	0.211					
Lagged change in catchment population, $\Delta P_{(t-1)-(t-2)}$	2.77E-05	1.31E-04	0.833					
Lagged change in GDP-per-capita, $\Delta G_{(t-1)-(t-2)}$	1.74E-02	5.06E-03	0.001	0.985				
WWI	-4.86E+00	1.27E+01	0.703					
WWII	8.096E+01	1.12E+01	0.000					
Constant	2.22E+01	5.69E+00	0.000					
Lagged 45-minute net access, $A_{45p,t-2}$					9.23E-01	1.39E-02	0.000	
Lagged change in ridership, $R_{t-(t-1)}$					1.26E+02	3.46E+01	0.000	
Lagged change in catchment population, $\Delta P_{t-(t-1)}$					8.74E-02	2.58E-02	0.001	
Lagged change in GDP-per-capita, $\Delta G_{t-(t-1)}$					-2.38E+00	1.19E+00	0.048	0.977
WWI					2.67E+03	3.08E+03	0.389	
WWII					-6.71E+02	3.07E+03	0.827	
Constant					9.56E+03	1.83E+03	0.000	

Catchment population indicates people living within 15-minute walking radius of public transport stations.

GDP per-capita values are inflation adjusted and available in 2011 USD from Bolt and Van Zanden, 2020.

Table A.5: Aggregate public transport ridership, R_t, and 60-, minute net access to population, $A_{60p,t}$, estimated with WWI and WWII as explanatory variables: 1876 to 2014 ($N = 137$)

	Coeff.	S.E.	p	R^2	Coeff.	S.E.	p	R^2
	Dependent variable: R_t				Dependent variable: $A_{60p,t}$			
Lagged ridership, R_{t-2}	9.44E-01	1.35E-02	0.000					
Lagged change in 60-minute net access, $\Delta A_{60p,(t-1)-(t-2)}$	5.23E-04	3.53E-04	0.141					
Lagged change in catchment population, $\Delta P_{(t-1)-(t-2)}$	1.47E-05	1.31E-04	0.911					
Lagged change in GDP-per-capita, $\Delta G_{(t-1)-(t-2)}$	1.74E-02	5.04E-03	0.001	0.985				
WWI	-6.05E+00	1.27E+01	0.635					
WWII	8.085E+01	1.11E+01	0.000					
Constant	2.21E+01	5.60E+00	0.000					
Lagged 60-minute net access, $A_{60p,t-2}$					9.45E-01	1.14E-02	0.000	
Lagged change in ridership, $R_{t-(t-1)}$					1.36E+02	5.90E+01	0.023	
Lagged change in catchment population, $\Delta P_{t-(t-1)}$					1.95E-01	4.36E-02	0.000	
Lagged change in GDP-per-capita, $\Delta G_{t-(t-1)}$					-6.12E-01	2.03E+00	0.763	0.988
WWI					5.57E+03	4.99E+03	0.267	
WWII					1.53E+03	5.14E+03	0.766	
Constant					1.27E+04	2.76E+03	0.000	

Catchment population indicates people living within 15-minute walking radius of public transport stations.

GDP per-capita values are inflation adjusted and available in 2011 USD from Bolt and Van Zanden, 2020.

A.3 Causal models compared with S-curves

Table A.6 and Table A.7 present results from the temporally segregated models for public transport ridership and 45-minute net access to population respectively. The goodness of fits of these models were compared with those from S-curve models in Table 5.5.

Table A.6: Temporally segregated models: Aggregate public transport ridership, R_t

	Coeff.	S.E.	p	R^2
1876 to 1938 ($N = 61$)				
Lagged ridership, R_{t-2}	1.01E+00	2.03E-02	0.000	
Lagged change in 45-minute access, $\Delta A_{45,(t-1)-(t-2)}$	6.19E-04	6.77E-04	0.364	
Lagged change in catchment population, $\Delta P_{(t-1)-(t-2)}$	2.83E-05	1.83E-04	0.877	0.984
Lagged change in GDP-per-capita, $\Delta G_{(t-1)-(t-2)}$	2.48E-02	8.52E-03	0.005	
Constant	1.22E+01	5.66E+00	0.035	
1946 to 1978 ($N = 30$)				
Lagged ridership, R_{t-2}	9.33E-01	4.68E-02	0.000	
Lagged change in 45-minute access, $\Delta A_{45,(t-1)-(t-2)}$	-8.92E-04	1.69E-03	0.601	
Lagged change in catchment population, $\Delta P_{(t-1)-(t-2)}$	-9.17E-05	3.03E-04	0.765	0.948
Lagged change in GDP-per-capita, $\Delta G_{(t-1)-(t-2)}$	3.21E-02	1.76E-02	0.080	
Constant	6.76E+00	3.03E+01	0.825	
1979 to 2014 ($N = 34$)				
Lagged ridership, R_{t-2}	8.19E-01	8.66E-02	0.000	
Lagged change in 45-minute access, $\Delta A_{45,(t-1)-(t-2)}$	5.32E-07	1.41E-04	1.000	
Lagged change in catchment population, $\Delta P_{(t-1)-(t-2)}$	2.90E-04	1.44E-04	0.053	0.878
Lagged change in GDP-per-capita, $\Delta G_{(t-1)-(t-2)}$	1.45E-02	5.92E-03	0.020	
Constant	8.39E+01	4.57E+01	0.076	

Catchment population indicates people living within 15-minute walking radius of public transport stations.

GDP per-capita values are inflation adjusted and available in 2011 USD from Bolt and Van Zanden, 2020.

Table A.7: Temporally segregated models: 45-minute net aggregate public transport access to population, $A_{45,t}$

	Coeff.	S.E.	p	R^2
1876 to 1946 ($N = 69$)				
Lagged 45-minute access, $A_{45,t-2}$	9.33E-01	1.57E-02	0.000	
Lagged change in ridership, $R_{t-(t-1)}$	5.97E+01	5.39E+01	0.272	
Lagged change in catchment population, $\Delta P_{t-(t-1)}$	1.25E-01	4.37E-02	0.006	0.985
Lagged change in GDP-per-capita, $\Delta G_{t-(t-1)}$	-1.00E+00	2.39E+00	0.677	
Constant	1.01E+04	2.05E+03	0.000	
1947 to 1990 ($N = 42$)				
Lagged 45-minute access, $A_{45,t-2}$	9.03E-01	2.58E-02	0.000	
Lagged change in ridership, $R_{t-(t-1)}$	-5.29E+01	4.08E+01	0.203	
Lagged change in catchment population, $\Delta P_{t-(t-1)}$	9.20E-02	3.50E-02	0.012	0.981
Lagged change in GDP-per-capita, $\Delta G_{t-(t-1)}$	9.83E-01	1.60E+00	0.543	
Constant	5.69E+03	3.63E+03	0.125	
1991 to 2014 ($N = 22$)				
Lagged 45-minute access, $A_{45,t-2}$	9.64E-01	6.64E-02	0.000	
Lagged change in ridership, $R_{t-(t-1)}$	-7.85E+01	7.17E+01	0.289	
Lagged change in catchment population, $\Delta P_{t-(t-1)}$	9.68E-02	2.57E-02	0.002	0.963
Lagged change in GDP-per-capita, $\Delta G_{t-(t-1)}$	-3.16E+00	2.41E+00	0.206	
Constant	8.09E+03	9.15E+03	0.389	

Catchment population indicates people living within 15-minute walking radius of public transport stations.

GDP per-capita values are inflation adjusted and available in 2011 USD from Bolt and Van Zanden, 2020.

A.4 Model estimates: Disaggregate station ridership and access

This sections documents results from causal models estimated for disaggregated station ridership and access.

Table A.8, Table A.9, and Table A.10 present results from models estimating station ridership and 45- and 60-minute net public transport access for the time periods 1877 to 1940, 1976 to 1990, and 2001 to 2012 respectively.

Additionally, models estimated with changes in station ridership and access as dependent variables are presented by time period in Table A.11, Table A.12 and Table A.13.

Table A.8: Disaggregate train ridership, R_t, and 45- and 60-minute net access to population, $A_{45p,t}$ and $A_{60p,t}$: 1877 to 1940

	Coeff.	S.E.	p	R^2	Coeff.	S.E.	p	R^2
	Dependent variable: R_t				Dependent variable: $A_{45p,t}$			
Lagged ridership, R_{t-2}	1.03E+00	1.74E-03	0.000					
Lagged change in 45-minute net access, $\Delta A_{45p,(t-1)-(t-2)}$	1.58E+00	2.19E-01	0.000					
Lagged change in catchment population, $\Delta P_{(t-1)-(t-2)}$	5.54E+01	1.64E+01	0.001	0.985				
Lagged change in GDP-per-capita, $\Delta G_{(t-1)-(t-2)}$	7.61E+01	5.30E+00	0.000					
Distance to Central station, D	-1.01E+03	1.52E+02	0.000					
Constant	4.45E+04	4.77E+03	0.000					
Lagged 45-minute net access, $A_{45p,t-2}$					1.01E+00	2.08E-03	0.000	
Lagged change in ridership, $R_{t-(t-1)}$					3.98E-04	1.39E-04	0.004	
Lagged change in catchment population, $\Delta P_{t-(t-1)}$					6.49E+00	1.25E+00	0.000	0.986
Lagged change in GDP-per-capita, $\Delta G_{t-(t-1)}$					-7.25E-02	3.93E-01	0.854	
Distance to Central station, D					-1.83E+02	1.32E+01	0.000	
Constant					7.09E+03	4.27E+02	0.000	
	Dependent variable: $\Delta R_{t-(t-1)}$				Dependent variable: $\Delta A_{60,t-(t-1)}$			
Lagged ridership, R_{t-2}	1.03E+00	1.74E-03	0.000					
Lagged change in 60-minute net access, $\Delta A_{60p,(t-1)-(t-2)}$	5.56E-01	1.18E-01	0.000					
Lagged change in catchment population, $\Delta P_{(t-1)-(t-2)}$	5.99E+01	1.65E+01	0.000	0.984				
Lagged change in GDP-per-capita, $\Delta G_{(t-1)-(t-2)}$	7.64E+01	5.31E+00	0.000					
Distance to Central station, D	-1.07E+03	1.53E+02	0.000					
Constant	4.61E+04	4.82E+03	0.000					
Lagged 60-minute net access, $A_{60p,t-2}$					1.02E+00	2.23E-03	0.000	
Lagged change in ridership, $R_{t-(t-1)}$					2.07E-02	2.98E-03	0.000	
Lagged change in catchment population, $\Delta P_{t-(t-1)}$					1.76E+00	2.32E+00	0.449	0.982
Lagged change in GDP-per-capita, $\Delta G_{t-(t-1)}$					-4.65E-01	7.42E-01	0.531	
Distance to Central station, D					-3.74E+02	2.55E+01	0.000	
Constant					1.56E+04	8.63E+02	0.000	

Unbalanced panel with 62 time periods (avg. 42) and 159 stations (avg. 108).

Catchment population indicates people living within 15-minute walking radius of public transport stations.

GDP per-capita values are inflation adjusted and available in 2011 USD from Bolt and Van Zanden, 2020.

Table A.9: Disaggregate train ridership, R_t, and 45- and 60-minute net access to population, $A_{45p,t}$ and $A_{60p,t}$: 1976 to 1990

	Coeff.	S.E.	p	R^2	Coeff.	S.E.	p	R^2
	Dependent variable: R_t				Dependent variable: $A_{45p,t}$			
Lagged ridership, R_{t-2}	1.00E+00	6.17E-03	0.000	0.935				
Lagged change in 45-minute net access, $\Delta A_{45p,(t-1)-(t-2)}$	1.69E+00	6.95E-01	0.015					
Lagged change in catchment population, $\Delta P_{(t-1)-(t-2)}$	-2.05E+00	2.27E+01	0.928					
Lagged change in GDP-per-capita, $\Delta G_{(t-1)-(t-2)}$	6.14E+01	1.14E+01	0.000					
Distance to Central station, D	-3.26E+02	4.36E+02	0.455					
Constant	1.82E+04	1.47E+04	0.215					
Lagged 45-minute net access, $A_{45p,t-2}$					9.54E-01	4.01E-03	0.000	0.989
Lagged change in ridership, $R_{t-(t-1)}$					1.37E-03	2.72E-04	0.000	
Lagged change in catchment population, $\Delta P_{t-(t-1)}$					8.87E-01	9.99E-01	0.375	
Lagged change in GDP-per-capita, $\Delta G_{t-(t-1)}$					8.35E-01	5.01E-01	0.096	
Distance to Central station, D					-1.67E+02	3.07E+01	0.000	
Constant					9.10E+03	1.25E+03	0.000	
	Dependent variable: $\Delta R_{t-(t-1)}$				Dependent variable: $\Delta A_{60,t-(t-1)}$			
Lagged ridership, R_{t-2}	1.00E+00	6.16E-03	0.000	0.935				
Lagged change in 60-minute net access, $\Delta A_{60p,(t-1)-(t-2)}$	1.36E+00	3.99E-01	0.001					
Lagged change in catchment population, $\Delta P_{(t-1)-(t-2)}$	-1.30E+00	2.27E+01	0.954					
Lagged change in GDP-per-capita, $\Delta G_{(t-1)-(t-2)}$	6.09E+01	1.14E+01	0.000					
Distance to Central station, D	-3.723E+02	4.36E+02	0.394					
Constant	1.85E+04	1.47E+04	0.206					
Lagged 60-minute net access, $A_{60p,t-2}$					9.65E-01	3.44E-03	0.000	0.992
Lagged change in ridership, $R_{t-(t-1)}$					8.92E-03	2.81E-03	0.002	
Lagged change in catchment population, $\Delta P_{t-(t-1)}$					4.23E-01	1.85E+00	0.819	
Lagged change in GDP-per-capita, $\Delta G_{t-(t-1)}$					1.24E+00	9.31E-01	0.183	
Distance to Central station, D					-3.00E+02	5.86E+01	0.000	
Constant					1.97E+04	2.52E+03	0.000	

Unbalanced panel with 13 time periods (avg. 13) and 165 stations (avg. 163).

Catchment population indicates people living within 15-minute walking radius of public transport stations.

GDP per-capita values are inflation adjusted and available in 2011 USD from Bolt and Van Zanden, 2020.

Table A.10: Disaggregate train ridership, R_t, and 45- and 60-minute net access to population, $A_{45p,t}$ and $A_{60p,t}$, 45- and 60-minute net access to jobs, $A_{45j,t}$ and $A_{60j,t}$: 2001 to 2012

	Coeff.	S.E.	p	R^2	Coeff.	S.E.	p	R^2
	Dependent variable: R_t				Dependent variable: R_t			
Lagged ridership, R_{t-2}	1.02E+00	2.40E-03	0.000		1.02E+00	2.40E-03	0.000	
Lagged change in 45-minute net access, $\Delta A_{45p,(t-1)-(t-2)}$	-1.96E-01	3.47E-01	0.572					
Lagged change in 45-minute net access to jobs, $\Delta A_{45j,(t-1)-(t-2)}$					3.85E-01	2.54E-01	0.129	
Lagged change in catchment population, $\Delta P_{(t-1)-(t-2)}$	1.43E+02	2.10E+01	0.000	0.992	1.38E+02	2.09E+01	0.000	0.992
Lagged change in GDP-per-capita, $\Delta G_{(t-1)-(t-2)}$	-9.39E+00	9.12E+00	0.303		-6.94E+00	9.09E+00	0.445	
Distance to Central station, D	-1.06E+03	2.52E+02	0.000		-1.00E+03	2.52E+02	0.000	
Constant	3.26E+04	1.14E+04	0.004		2.81E+04	1.14E+04	0.014	
	Dependent variable: $A_{45p,t}$				Dependent variable: $A_{45j,t}$			
Lagged 45-minute net access, $A_{45p,t-2}$	1.01E+00	4.31E-03	0.000					
Lagged 45-minute net access to jobs, $A_{45j,t-2}$					1.03E+00	3.96E-03	0.000	
Lagged change in ridership, $R_{t-(t-1)}$	1.81E-05	2.24E-04	0.936		-3.49E-04	2.58E-04	0.176	
Lagged change in catchment population, $\Delta P_{t-(t-1)}$	1.11E+01	1.54E+00	0.000	0.991	1.23E+01	1.87E+00	0.000	0.990
Lagged change in GDP-per-capita, $\Delta G_{t-(t-1)}$	-8.90E+00	8.58E-01	0.000		-9.68E+00	1.04E+00	0.000	
Distance to Central station, D	-7.99E+01	3.66E+01	0.029		-2.58E+01	4.08E+01	0.527	
Constant	1.07E+04	1.64E+03	0.000		8.94E+03	1.68E+03	0.000	
	Dependent variable: R_t				Dependent variable: R_t			
Lagged ridership, R_{t-2}	1.02E+00	2.40E-03	0.000		1.02E+00	2.40E-03	0.000	
Lagged change in 60-minute net access, $\Delta A_{60p,(t-1)-(t-2)}$	-3.00E-02	1.60E-01	0.852					
Lagged change in 60-minute net access to jobs, $\Delta A_{60j,(t-1)-(t-2)}$					8.99E-02	2.01E-01	0.655	
Lagged change in catchment population, $\Delta P_{(t-1)-(t-2)}$	1.42E+02	2.09E+01	0.000	0.992	1.41E+02	2.10E+01	0.000	0.992
Lagged change in GDP-per-capita, $\Delta G_{(t-1)-(t-2)}$	-8.91E+00	9.14E+00	0.330		-8.01E+00	9.13E+00	0.381	
Distance to Central station, D	-1.05E+03	2.51E+02	0.000		-1.03E+03	2.54E+02	0.000	
Constant	3.18E+04	1.15E+04	0.006		2.99E+04	1.16E+04	0.010	
	Dependent variable: $A_{60p,t}$				Dependent variable: $A_{60j,t}$			
Lagged 60-minute net access, $A_{60p,t-2}$	1.01E+00	4.44E-03	0.000					
Lagged 60-minute net access to jobs, $A_{60j,t-2}$					1.04E+00	3.99E-03	0.000	
Lagged change in ridership, $R_{t-(t-1)}$	-1.03E-03	8.34E-03	0.902		-9.61E-04	6.57E-03	0.884	
Lagged change in catchment population, $\Delta P_{t-(t-1)}$	2.02E+01	3.31E+00	0.000	0.990	1.72E+01	2.60E+00	0.000	0.992
Lagged change in GDP-per-capita, $\Delta G_{t-(t-1)}$	-1.86E+01	1.83E+00	0.000		-1.83E+01	1.45E+00	0.000	
Distance to Central station, D	-1.34E+02	8.17E+01	0.100		2.71E+01	6.26E+01	0.665	
Constant	2.23E+04	3.90E+03	0.000		1.38E+04	2.73E+03	0.000	

Unbalanced panel with 10 time periods (avg. 10) and 174 stations (avg. 172).

Catchment population indicates people living within 15-minute walking radius of public transport stations.

GDP per-capita values are inflation adjusted and available in 2011 USD from Bolt and Van Zanden, 2020.

Table A.11: Change in disaggregate station ridership, $\Delta R_{t-(t-2)}$, and change in 30-, 45- and 60-minute net access to population, $\Delta A_{30p,t-(t-2)}$, $\Delta A_{45p,t-(t-2)}$ and $\Delta A_{60p,t-(t-2)}$: 1877 to 1940

	Coeff.	S.E.	p	R^2	Coeff.	S.E.	p	R^2
	Dependent variable: $\Delta R_{t-(t-2)}$				Dependent variable: $\Delta A_{30p,t-(t-2)}$			
Lagged change in 30-minute net access, $\Delta A_{30p,(t-1)-(t-2)}$	4.16E+00	7.22E-01	0.000					
Lagged change in catchment population, $\Delta P_{(t-1)-(t-2)}$	5.77E+01	1.70E+01	0.001					
Lagged change in GDP-per-capita, $\Delta G_{(t-1)-(t-2)}$	7.65E+01	5.44E+01	0.000	0.080				
Distance to Central station, D	-2.05E+03	1.45E+02	0.000					
Constant	8.67E+04	4.30E+03	0.000					
Lagged change in ridership, $R_{t-(t-1)}$					4.16E-03	4.95E-04	0.000	
Lagged change in catchment population, $\Delta P_{t-(t-1)}$					5.35E+00	3.85E-01	0.000	
Lagged change in GDP-per-capita, $\Delta G_{t-(t-1)}$					-1.89E-01	1.23E-01	0.124	0.117
Distance to Central station, D					-5.51E+01	3.31E+00	0.000	
Constant					1.99E+03	1.82E+02	0.000	
	Dependent variable: $\Delta R_{t-(t-2)}$				Dependent variable: $\Delta A_{45p,t-(t-2)}$			
Lagged change in 45-minute net access, $\Delta A_{45p,(t-1)-(t-2)}$	1.73E+00	2.24E-01	0.000					
Lagged change in catchment population, $\Delta P_{(t-1)-(t-2)}$	6.43E+01	1.68E+01	0.000					
Lagged change in GDP-per-capita, $\Delta G_{(t-1)-(t-2)}$	7.67E+01	5.42E+00	0.000	0.084				
Distance to Central station, D	-1.96E+03	1.46E+02	0.000					
Constant	8.29E+04	4.36E+03	0.000					
Lagged change in ridership, $R_{t-(t-1)}$					1.68E-02	1.60E-03	0.000	
Lagged change in catchment population, $\Delta P_{t-(t-1)}$					5.75E+00	1.24E+00	0.000	
Lagged change in GDP-per-capita, $\Delta G_{t-(t-1)}$					-5.49E-01	3.97E-01	0.166	0.113
Distance to Central station, D					-2.29E+02	1.07E+01	0.000	
Constant					8.76E+03	3.17E+02	0.000	
	Dependent variable: $\Delta R_{t-(t-2)}$				Dependent variable: $\Delta A_{60p,t-(t-2)}$			
Lagged change in 60-minute net access, $\Delta A_{60p,(t-1)-(t-2)}$	6.39E-01	1.21E-01	0.000					
Lagged change in catchment population, $\Delta P_{(t-1)-(t-2)}$	6.92E+01	1.68E+01	0.000					
Lagged change in GDP-per-capita, $\Delta G_{(t-1)-(t-2)}$	7.71E+01	5.44E+00	0.000	0.079				
Distance to Central station, D	-2.01E+03	1.47E+02	0.000					
Constant	8.45E+04	4.42E+03	0.000					
Lagged change in ridership, $R_{t-(t-1)}$					2.13E-02	2.99E-03	0.000	
Lagged change in catchment population, $\Delta P_{t-(t-1)}$					1.80E+00	2.33E+00	0.439	
Lagged change in GDP-per-capita, $\Delta G_{t-(t-1)}$					-7.52E-02	7.42E-01	0.919	0.107
Distance to Central station, D					-4.81E+02	2.00E+01	0.000	
Constant					1.98E+04	5.94E+02	0.000	

Unbalanced panel with 64 time periods (avg. 44) and 159 stations (avg. 110).

Catchment population indicates people living within 15-minute walking radius of public transport stations.

GDP per-capita values are inflation adjusted and available in 2011 USD from Bolt and Van Zanden, 2020.

Table A.12: Change in disaggregate station ridership, $\Delta R_{t-(t-2)}$, and change in 30-, 45- and 60-minute net access to population, $\Delta A_{30p,t-(t-2)}$, $\Delta A_{45p,t-(t-2)}$ and $\Delta A_{60p,t-(t-2)}$: 1976 to 1990

	Coeff.	S.E.	p	R^2	Coeff.	S.E.	p	R^2
	Dependent variable: $\Delta R_{t-(t-2)}$				Dependent variable: $\Delta A_{30p,t-(t-2)}$			
Lagged change in 30-minute net access, $\Delta A_{30p,(t-1)-(t-2)}$	9.33E+00	2.15E+00	0.000					
Lagged change in catchment population, $\Delta P_{(t-1)-(t-2)}$	-5.09E+00	2.25E+00	0.821					
Lagged change in GDP-per-capita, $\Delta G_{(t-1)-(t-2)}$	6.13E+01	1.13E+01	0.000	0.023				
Distance to Central station, D	-3.56E+02	4.11E+02	0.387					
Constant	1.88E+04	1.18E+04	0.111					
Lagged change in ridership, $R_{t-(t-1)}$					2.40E-03	5.23E-04	0.000	
Lagged change in catchment population, $\Delta P_{t-(t-1)}$					6.08E-01	3.45E-01	0.078	
Lagged change in GDP-per-capita, $\Delta G_{t-(t-1)}$					9.18E-02	1.74E-01	0.597	0.022
Distance to Central station, D					2.78E+01	6.27E+00	0.000	
Constant					-7.37E+02	1.80E+02	0.000	
	Dependent variable: $\Delta R_{t-(t-2)}$				Dependent variable: $\Delta A_{45p,t-(t-2)}$			
Lagged change in 45-minute net access, $\Delta A_{45p,(t-1)-(t-2)}$	1.69E+00	6.95E-01	0.015					
Lagged change in catchment population, $\Delta P_{(t-1)-(t-2)}$	-1.95E+00	2.25E+01	0.931					
Lagged change in GDP-per-capita, $\Delta G_{(t-1)-(t-2)}$	6.14E+01	1.14E+01	0.000	0.017				
Distance to Central station, D	-3.20E+02	4.13E+02	0.438					
Constant	1.78E+04	1.18E+04	0.131					
Lagged change in ridership, $R_{t-(t-1)}$					3.95E-03	1.55E-03	0.011	
Lagged change in catchment population, $\Delta P_{t-(t-1)}$					3.54E-01	1.02E+00	0.730	
Lagged change in GDP-per-capita, $\Delta G_{t-(t-1)}$					8.24E-01	5.16E-01	0.110	0.018
Distance to Central station, D					9.88E+01	1.86E+01	0.000	
Constant					-2.52E+03	5.33E+02	0.000	
	Dependent variable: $\Delta R_{t-(t-2)}$				Dependent variable: $\Delta A_{60p,t-(t-2)}$			
Lagged change in 60-minute net access, $\Delta A_{60p,(t-1)-(t-2)}$	1.36E+00	3.99-01	0.001					
Lagged change in catchment population, $\Delta P_{(t-1)-(t-2)}$	-1.30E+00	2.25E+01	0.954					
Lagged change in GDP-per-capita, $\Delta G_{(t-1)-(t-2)}$	6.09E+01	1.14E+01	0.000	0.019				
Distance to Central station, D	-3.72E+02	4.13E+02	0.367					
Constant	1.86E+04	1.18E+04	0.116					
Lagged change in ridership, $R_{t-(t-1)}$					9.96E-03	2.87E-03	0.001	
Lagged change in catchment population, $\Delta P_{t-(t-1)}$					5.34E-01	1.89E+00	0.778	
Lagged change in GDP-per-capita, $\Delta G_{t-(t-1)}$					1.31E+00	9.53E-01	0.171	0.021
Distance to Central station, D					1.93E+02	3.44E+01	0.000	
Constant					-4.22E+03	9.86E+02	0.000	

Unbalanced panel with 14 time periods (avg. 14) and 165 stations (avg. 163).

Catchment population indicates people living within 15-minute walking radius of public transport stations.

GDP per-capita values are inflation adjusted and available in 2011 USD from Bolt and Van Zanden, 2020.

Table A.13: Change in disaggregate station ridership, $\Delta R_{t-(t-2)}$, change in 30-, 45- and 60-minute net access to population, $\Delta A_{30p,t-(t-2)}$, $\Delta A_{45p,t-(t-2)}$ and $\Delta A_{60p,t-(t-2)}$, and change in 30-, 45- and 60-minute net access to jobs, $\Delta A_{30j,t-(t-2)}$, $\Delta A_{45j,t-(t-2)}$ and $\Delta A_{60j,t-(t-2)}$: 2001 to 2012

	Coeff.	S.E.	p	R^2	Coeff.	S.E.	p	R^2
	Dependent variable: $\Delta R_{t-(t-2)}$				Dependent variable: $\Delta R_{t-(t-2)}$			
Lagged change in 30-minute net access to population, $\Delta A_{30p,(t-1)-(t-2)}$	2.44E+00	1.13E+00	0.031					
Lagged change in 30-minute net access to jobs, $\Delta A_{30j,(t-1)-(t-2)}$					1.86E+00	5.61E-01	0.001	
Lagged change in catchment population, $\Delta P_{(t-1)-(t-2)}$	1.65E+02	2.12E+01	0.000	0.072	1.63E+02	2.11E+01	0.000	0.075
Lagged change in GDP-per-capita, $\Delta G_{(t-1)-(t-2)}$	-5.03E+00	9.29E+00	0.589		-5.03E+00	9.22E+00	0.585	
Distance to Central station, D	-1.56E+03	2.48E+02	0.000		-1.52E+03	2.47E+02	0.000	
Constant	6.14E+04	1.08E+04	0.000		6.06E+04	1.08E+04	0.000	
	Dependent variable: $\Delta A_{30p,t-(t-2)}$				Dependent variable: $\Delta A_{30j,t-(t-2)}$			
Lagged change in ridership, $R_{t-(t-1)}$	3.02E-03	1.27E-03	0.017		9.40E-03	2.46E-03	0.000	
Lagged change in catchment population, $\Delta P_{t-(t-1)}$	4.20E+00	5.01E-01	0.000		5.05E+00	9.71E-01	0.000	
Lagged change in GDP-per-capita, $\Delta G_{t-(t-1)}$	-2.54E+00	2.80E-01	0.000	0.131	-3.05E+00	5.42E-01	0.000	0.094
Distance to Central station, D	-4.37E+01	7.21E+00	0.000		-1.04E+02	1.40E+01	0.000	
Constant	3.84E+03	3.11E+02	0.000		5.95E+03	6.03E+02	0.000	
	Dependent variable: $\Delta R_{t-(t-2)}$				Dependent variable: $\Delta R_{t-(t-2)}$			
Lagged change in 45-minute net access to population, $\Delta A_{45p,(t-1)-(t-2)}$	-1.16E-01	3.54E-01	0.744					
Lagged change in 45-minute net access to jobs, $\Delta A_{45j,(t-1)-(t-2)}$					3.70E-01	2.59E-01	0.153	
Lagged change in catchment population, $\Delta P_{(t-1)-(t-2)}$	1.72E+02	2.11E+01	0.000	0.069	1.68E+02	2.11E+01	0.000	0.070
Lagged change in GDP-per-capita, $\Delta G_{(t-1)-(t-2)}$	-8.09E+00	9.32E+00	0.385		-6.01E+00	9.28E+00	0.518	
Distance to Central station, D	-1.61E+03	2.49E+02	0.000		-1.56E+03	2.49E+02	0.000	
Constant	6.64E+04	1.10E+04	0.000		6.26E+04	1.09E+04	0.000	
	Dependent variable: $\Delta A_{45p,t-(t-2)}$				Dependent variable: $\Delta A_{45j,t-(t-2)}$			
Lagged change in ridership, $R_{t-(t-1)}$	-1.84E-03	3.90E-03	0.636		7.92E-03	4.80E-03	0.099	
Lagged change in catchment population, $\Delta P_{t-(t-1)}$	1.18E+01	1.54E+00	0.000		1.17E+01	1.90E+00	0.000	
Lagged change in GDP-per-capita, $\Delta G_{t-(t-1)}$	-8.88E+00	8.61E-01	0.000	0.139	-9.77E+00	1.06E+00	0.000	0.135
Distance to Central station, D	-1.78E+02	2.22E+01	0.000		-2.57E+02	2.73E+01	0.000	
Constant	1.53E+04	9.57E+02	0.000		1.77E+04	1.18E+03	0.000	
	Dependent variable: $\Delta R_{t-(t-2)}$				Dependent variable: $\Delta R_{t-(t-2)}$			
Lagged change in 60-minute net access to population, $\Delta A_{60p,(t-1)-(t-2)}$	-2.88E-02	1.64E-01	0.860					
Lagged change in 60-minute net access to jobs, $\Delta A_{60j,(t-1)-(t-2)}$					5.16E-02	2.06E-01	0.802	
Lagged change in catchment population, $\Delta P_{(t-1)-(t-2)}$	1.72E+02	2.11E+01	0.000	0.069	1.71E+02	2.12E+01	0.000	0.069
Lagged change in GDP-per-capita, $\Delta G_{(t-1)-(t-2)}$	-7.91E+00	9.34E+00	0.397		-7.29E+00	9.33E+00	0.435	
Distance to Central station, D	-1.61E+03	2.48E+02	0.000		-1.59E+03	2.51E+02	0.000	
Constant	6.61E+04	1.10E+04	0.000		6.48E+04	1.11E+04	0.000	
	Dependent variable: $\Delta A_{60p,t-(t-2)}$				Dependent variable: $\Delta A_{60j,t-(t-2)}$			
Lagged change in ridership, $R_{t-(t-1)}$	1.49E-03	8.30E-03	0.858		2.95E-03	6.73E-03	0.662	
Lagged change in catchment population, $\Delta P_{t-(t-1)}$	2.14E+01	3.29E+00	0.000		1.91E+01	2.66E+00	0.000	
Lagged change in GDP-per-capita, $\Delta G_{t-(t-1)}$	-1.85E+01	1.83E+00	0.000	0.118	-1.86E+01	1.49E+00	0.000	0.195
Distance to Central station, D	-3.19E+02	4.73E+01	0.000		-4.52E+02	3.83E+01	0.000	
Constant	3.15E+04	2.04E+03	0.000		3.47E+04	1.65E+03	0.000	

Unbalanced panel with 11 time periods (avg. 11) and 174 stations (avg. 172).

Catchment population indicates people living within 15-minute walking radius of public transport stations.

GDP per-capita values are inflation adjusted and available in 2011 USD from Bolt and Van Zanden, 2020.

A.5 Estimates of models with wars as dummy variables: Disaggregate station ridership and access during 1877 to 1940

Table A.14, Table A.15, and Table A.16 present the results from causal models estimated on train station ridership and net 30-, 45-, and 60-mintue public transport access to population from stations with years under World War I (WWI) and World War II (WWII) included as dummy variables respectively.

Table A.14: Disaggregate train ridership, R_t, and 30-minute net access to population, $A_{30p,t}$, estimated with WWI and WWII as explanatory variables: 1877 to 1940

	Coeff.	S.E.	p	R^2	Coeff.	S.E.	p	R^2
	Dependent variable: R_t				Dependent variable: $A_{30p,t}$			
Lagged ridership, R_{t-2}	1.03E+00	1.74E-03	0.000	0.985				
Lagged change in 30-minute net access, $\Delta A_{30p,(t-1)-(t-2)}$	3.86E+00	7.01E-01	0.000					
Lagged change in catchment population, $\Delta P_{(t-1)-(t-2)}$	4.16E+01	1.66E+01	0.012					
Lagged change in GDP-per-capita, $\Delta G_{(t-1)-(t-2)}$	7.76E+01	5.32E+00	0.000					
Distance to Central station, D	-1.08E+03	1.51E+02	0.000					
WWI	9.79E+03	6.62E+03	0.139					
WWII	-7.97E+04	8.81E+03	0.000					
Constant	4.96E+04	4.73E+03	0.000					
Lagged 30-minute net access, $A_{30p,t-2}$					1.01E+00	1.65E-03	0.000	0.990
Lagged change in ridership, $R_{t-(t-1)}$					9.41E-05	4.26E-05	0.027	
Lagged change in catchment population, $\Delta P_{t-(t-1)}$					5.71E+00	3.90E-01	0.000	
Lagged change in GDP-per-capita, $\Delta G_{t-(t-1)}$					-6.64E-02	1.25E-01	0.594	
Distance to Central station, D					-4.32E+01	3.95E+00	0.000	
WWI					-1.97E+02	1.58E+02	0.213	
WWII					-3.94E+02	2.08E+02	0.058	
Constant					1.61E+03	1.25E+02	0.000	

Unbalanced panel with 62 time periods (avg. 42) and 159 stations (avg. 108).

Catchment population indicates people living within 15-minute walking radius of public transport stations.

GDP per-capita values are inflation adjusted and available in 2011 USD from Bolt and Van Zanden, 2020.

Table A.15: Disaggregate train ridership, R_t, and 45-minute net access to population, $A_{45p,t}$, estimated with WWI and WWII as explanatory variables: 1877 to 1940

	Coeff.	S.E.	p	R^2	Coeff.	S.E.	p	R^2
	Dependent variable: R_t				Dependent variable: $A_{45p,t}$			
Lagged ridership, R_{t-2}	1.03E+00	1.74E-03	0.000	0.985				
Lagged change in 45-minute net access, $\Delta A_{45p,(t-1)-(t-2)}$	1.59E+00	2.17E-01	0.000					
Lagged change in catchment population, $\Delta P_{(t-1)-(t-2)}$	4.78E+01	1.65E+01	0.004					
Lagged change in GDP-per-capita, $\Delta G_{(t-1)-(t-2)}$	7.77E+01	5.31E+00	0.000					
Distance to Central station, D	-1.01E+03	1.52E+02	0.000					
WWI	9.80E+03	6.61E+03	0.138					
WWII	-7.98E+04	8.80E+03	0.000					
Constant	4.64E+04	4.76E+03	0.000					
Lagged 45-minute net access, $A_{45p,t-2}$					1.01E+00	2.09E-03	0.000	0.986
Lagged change in ridership, $R_{t-(t-1)}$					4.10E-04	1.40E-04	0.003	
Lagged change in catchment population, $\Delta P_{t-(t-1)}$					6.56E+00	1.26E+00	0.000	
Lagged change in GDP-per-capita, $\Delta G_{t-(t-1)}$					-7.02E-02	4.03E-01	0.862	
Distance to Central station, D					-1.81E+02	1.32E+01	0.000	
WWI					-4.00E+02	5.12E+02	0.434	
WWII					-1.21E+03	6.75E+02	0.073	
Constant					7.10E+03	4.28E+02	0.000	

Unbalanced panel with 62 time periods (avg. 42) and 159 stations (avg. 108).

Catchment population indicates people living within 15-minute walking radius of public transport stations.

GDP per-capita values are inflation adjusted and available in 2011 USD from Bolt and Van Zanden, 2020.

Table A.16: Disaggregate train ridership, R_t, and 60-minute net access to population, $A_{60p,t}$, estimated with WWI and WWII as explanatory variables: 1877 to 1940

	Coeff.	S.E.	p	R^2	Coeff.	S.E.	p	R^2
	Dependent variable: $\Delta R_{t-(t-1)}$				Dependent variable: $\Delta A_{60,t-(t-1)}$			
Lagged ridership, R_{t-2}	1.03E+00	1.74E-03	0.000	0.985				
Lagged change in 60-minute net access, $\Delta A_{60p,(t-1)-(t-2)}$	5.76E-01	1.18E-01	0.000					
Lagged change in catchment population, $\Delta P_{(t-1)-(t-2)}$	5.23E+01	1.65E+01	0.002					
Lagged change in GDP-per-capita, $\Delta G_{(t-1)-(t-2)}$	7.81E+01	5.32E+00	0.000					
Distance to Central station, D	-1.05E+03	1.52E+02	0.000					
WWI	9.88E+03	6.62E+03	0.136					
WWII	-8.03E+04	8.82E+03	0.000					
Constant	4.79E+04	4.82E+03	0.000					
Lagged 60-minute net access, $A_{60p,t-2}$					1.01E+00	2.54E-03	0.000	0.982
Lagged change in ridership, $R_{t-(t-1)}$					7.74E-04	2.64E-04	0.000	
Lagged change in catchment population, $\Delta P_{t-(t-1)}$					2.56E+00	2.34E+00	0.275	
Lagged change in GDP-per-capita, $\Delta G_{t-(t-1)}$					2.16E-01	7.53E-01	0.774	
Distance to Central station, D					-3.87E+02	2.56E+01	0.000	
WWI					-1.22E+03	9.55E+02	0.202	
WWII					-1.44E+03	1.27E+03	0.257	
Constant					1.63E+04	8.63E+02	0.000	

Unbalanced panel with 62 time periods (avg. 42) and 159 stations (avg. 108).

Catchment population indicates people living within 15-minute walking radius of public transport stations.

GDP per-capita values are inflation adjusted and available in 2011 USD from Bolt and Van Zanden, 2020.

A.6 Model estimates: Public transport mode shares and net access to population and jobs

In Table A.17, I present the results from causal models estimated on mesh block public transport shares and 30- and 60-minute net public transport access to population and jobs for the period – 1991 to 2011.

Table A.17: Public transport mode share, S_t, 30- and 60-minute net access to population, $A_{30p,t}$ and $A_{60p,t}$, and 30- and 60-minute net access to jobs, $A_{30j,t}$ and $A_{60j,t}$: 1991 to 2011

	Coeff.	S.E.	p	R^2	Coeff.	S.E.	p	R^2
	Dependent variable: S_t				Dependent variable: S_t			
Lagged public transport share, S_{t-1}	8.60E-01	5.276E-03	0.000		8.51E-02	5.27E-03	0.000	
Lagged neighbours' public transport share, $\sum W_N S_{t-1}$	-3.78E-03	5.07E-03	0.456		-4.98E-04	5.06E-03	0.922	
Lagged change in 30-minute net access to population, $\Delta A_{30p,t-(t-1)}$	2.94E-05	5.27E-07	0.000					
Lagged change in 30-minute net access to jobs, $\Delta A_{30j,t-(t-1)}$				0.676	2.71E-05	4.33E-07	0.000	0.677
Lagged change in catchment population, $\Delta P_{t-(t-1)}$	9.11E-04	1.70E-05	0.000		9.08E-04	1.65E-05	0.000	
Lagged change in GDP-per-capita, $\Delta G_{t-(t-1)}$	3.25E-05	1.91E-06	0.000		2.01E-05	1.95E-06	0.000	
Constant	2.38E+00	1.60E-02	0.000		2.50E+00	1.65E-02	0.000	
	Dependent variable: $A_{30p,t}$				Dependent variable: $A_{30j,m,t}$			
Lagged 30-minute net access to population, $A_{30p,t-1}$	8.53E-01	1.05E-03	0.000					
Lagged 30-minute net access to jobs, $A_{30j,t-1}$					1.05E+00	1.12E-03	0.000	
Lagged change in public transport share, $S_{t-(t-1)}$	4.69E+02	1.23E+01	0.000	0.653	5.22E+02	1.81E+01	0.000	0.823
Lagged change in catchment population, $\Delta P_{t-(t-1)}$	4.20E+00	6.57E-02	0.000		3.00E+00	8.56E-02	0.000	
Lagged change in GDP-per-capita, $\Delta G_{t-(t-1)}$	-1.52E+00	8.87E-03	0.000		-1.04E+00	1.33E-02	0.000	
Constant	1.36E+04	4.73E+01	0.000		7.64E+03	5.37E+01	0.000	
	Dependent variable: S_t				Dependent variable: S_t			
Lagged public transport share, S_{t-1}	8.56E-01	5.25E-03	0.000		8.41E-02	5.25E-03	0.000	
Lagged neighbours' public transport share, $\sum W_N S_{t-1}$	-2.77E-03	5.06E-03	0.583		2.72E-03	5.04E-03	0.590	
Lagged change in 60-minute net access to population, $\Delta A_{60p,t-(t-1)}$	9.35E-06	1.21E-07	0.000					
Lagged change in 60-minute net access to jobs, $\Delta A_{60j,t-(t-1)}$				0.677	1.46E-05	1.61E-07	0.000	0.679
Lagged change in catchment population, $\Delta P_{t-(t-1)}$	9.07E-04	1.66E-05	0.000		8.84E-04	1.59E-05	0.000	
Lagged change in GDP-per-capita, $\Delta G_{t-(t-1)}$	3.76E-06	1.94E-06	0.053		-2.91E-05	2.05E-06	0.000	
Constant	2.44E+00	1.61E-02	0.000		2.62E+00	1.63E-02	0.000	
	Dependent variable: $A_{60p,t}$				Dependent variable: $A_{60j,t}$			
Lagged 60-minute net access to population, $A_{60p,t-1}$	9.88E-01	4.53E-04	0.000					
Lagged 60-minute net access to jobs, $A_{60j,t-1}$					1.06E+00	3.65E-04	0.000	
Lagged change in public transport share, $S_{t-(t-1)}$	2.47E+03	5.52E+01	0.000	0.865	1.49E+03	3.92E+01	0.000	0.919
Lagged change in catchment population, $\Delta P_{t-(t-1)}$	9.88E+00	2.27E-01	0.000		6.12E+00	2.19E-01	0.000	
Lagged change in GDP-per-capita, $\Delta G_{t-(t-1)}$	-3.91E+00	3.87E-02	0.000		-2.89E+00	3.50E-02	0.000	
Constant	4.29E+04	2.05E+02	0.000		2.71E+04	1.81E+02	0.000	

Lag = 5 years.

Balanced panel with 4 time periods and 58,819 mesh blocks.

Catchment population indicates people living within 15-minute walking radius of public transport stations.

GDP per-capita values are inflation adjusted and available in 2011 USD from Bolt and Van Zanden, 2020.

Bibliography

Abdallah, K. B., Belloumi, M., & Wolf, D. D. (2013). Indicators for sustainable energy development: A multivariate cointegration and causality analysis from Tunisian road transport sector. *Renewable and Sustainable Energy Reviews*, *25*, 34–43. https://doi.org/10.1016/J.RSER.2013.03.066

Ahlfeldt, G., Moeller, K., & Wendland, N. (2015). Chicken or egg? The PVAR econometrics of transportation. *Journal of Economic Geography*, *15*(6), 1169–1193.

Akinyemi, Y. C. (2018). Determinants of domestic air travel demand in Nigeria: Cointegration and causality analysis. *GeoJournal*, 1–18.

Antrim, A., & Barbeau, S. J. (2013). The many uses of GTFS data – opening the door to transit and multimodal applications. *Location-Aware Information Systems Laboratory at the University of South Florida*, *4*.

ARHS NSW Division. (2022). Australian Railway Historic Society. https://arhsnsw.com.au

Audley, D. (1983). Sydney's horse bus industry in 1889. In G. Wotherspoon (Ed.), *Sydney's Transport: Studies in Urban History* (pp. 81–100). Hale & Iremonger.

Australian Bureau of Statistics. (2005). *Informing a Nation: The Evolution of the Australian Bureau of Statistics 1905-2005*. Australian Bureau of Statistics.

Australian Bureau of Statistics. (2020). Table Builder. https://www.abs.gov.au/websitedbs/censushome.nsf/home/tablebuilder

Australian Bureau of Statistics. (2021a). Australian Statistical Geography Standard (ASGS): Volume 1 - Main Structure and Greater Capital City Statistical Areas, July 2016. https://www.abs.gov.au/ausstats/abs@.nsf/lookup/by%5C%20subject/1270.0.55.001~july%5C%202016~main%5C%20features~statistical%5C%20area%5C%20level%5C%202%5C%20(sa2)~10014

Australian Bureau of Statistics. (2021b). Mesh Blocks (MB). https://www.abs.gov.au/ausstats/abs@.nsf/Lookup/by%5C%20Subject/1270.0.55.001~July%5C%202016~Main%5C%20Features~Mesh%5C%20Blocks%5C%20(MB)~10012

Axhausen, K. (2008). Accessibility: Long-term perspectives. *Journal of Transport and Land Use*, *1*(2), 5–22.

Baker, D., Merkert, R., & Kamruzzaman, M. (2015). Regional aviation and economic growth: Cointegration and causality analysis in Australia. *Journal of Transport Geography*, *43*, 140–150.

Behrens, R. B., & Kane 1, L. A. (2004). Road capacity change and its impact on traffic in congested networks: Evidence and implications. *Development Southern Africa*, *21*(4), 587–602.

Biagi, B., & Pulina, M. (2009). Bivariate VAR models to test Granger causality between tourist demand and supply: Implications for regional sustainable growth. *Papers in Regional Science*, *88*(1), 231–244. https://doi.org/10.1111/j.1435-5957.2008.00176.x

Boeing, G. (2017). OSMnx: New methods for acquiring, constructing, analyzing, and visualizing complex street networks. *Computers, Environment and Urban Systems*, *65*, 126–139.

Bolt, J., & Van Zanden, J. L. (2020). Maddison style estimates of the evolution of the world economy: A new 2020 update. *Maddison-Project Working Paper WP-15, University of Groningen, Groningen, The Netherlands*. https://www.rug.nl/ggdc/historicaldevelopment/maddison/releases/maddison-project-database-2020

Bureau of Infrastructure, Transport and Regional Economics. (2014). Long-term trends in urban public transport. https://www.bitre.gov.au/publications/2014/is_060

Bureau of Infrastructure, Transport and Regional Economics. (2016). Lengthy commutes in Australia. https://www.bitre.gov.au/publications/2016/rr_144

Bureau of Transport Statistics. (2014). Train Statistics 2014. https://www.transport.nsw.gov.au/sites/default/files/media/documents/2017/Train%5C%20Statistics%5C%202014.pdf

Cervero, R., & Hansen, M. (2002). Induced travel demand and induced road investment. A simultaneous equation analysis. *Journal of Transport Economics and Policy*, *36*(3), 469–490.

Chen, Z., & Haynes, K. E. (2012). Re-examining linkages between surface transportation infrastructure and economic performance: A panel Granger Causality test on the Northeast corridor. *GMU School of Public Policy Research Paper*, (2013-02).

Chi, J., & Baek, J. (2013). Dynamic relationship between air transport demand and economic growth in the United States: A new look. *Transport Policy*, *29*, 257–260. https://doi.org/10.1016/J.TRANPOL.2013.03.005

Costa, A. B. (2018). *Transportation and urban development in São Paulo: Exploring how transportation has shaped and still shapes the city* (Doctoral dissertation).

Cui, B., Boisjoly, G., Miranda-Moreno, L., & El-Geneidy, A. (2020). Accessibility matters: Exploring the determinants of public transport mode share across income groups in canadian cities. *Transportation research part D: transport and environment*, *80*, 102276.

Danish, Baloch, M. A., & Suad, S. (2018). Modeling the impact of transport energy consumption on CO_2 emission in Pakistan: Evidence from ARDL approach. *Environmental Science and Pollution Research*, *25*(10), 9461–9473.

Diab, E., DeWeese, J., Chaloux, N., & El-Geneidy, A. (2021). Adjusting the service? understanding the factors affecting bus ridership over time at the route level in montréal, canada. *Transportation*, *48*, 2765–2786.

El-Geneidy, A., & Levinson, D. (2022). Making accessibility work in practice. *Transport Reviews*, *42*(2), 129–133.

El-Geneidy, A., Levinson, D., Diab, E., Boisjoly, G., Verbich, D., & Loong, C. (2016). The cost of equity: Assessing transit accessibility and social disparity using total travel cost. *Transportation Research Part A: Policy and Practice*, *91*, 302–316.

Evans, V. (1983). Early colonial shipping in and around Port Jackson. In G. Wotherspoon (Ed.), *Sydney's Transport: Studies in Urban History* (pp. 37–50). Hale & Iremonger.

Fernandes, E., & Pacheco, R. R. (2010). The causal relationship between GDP and domestic air passenger traffic in Brazil. *Transportation Planning and Technology*, *33*(7), 569–581. https://doi.org/10.1080/03081060.2010.512217

Flood, M., & Barbato, C. (2005). *Off to work: Commuting in Australia* (tech. rep.). The Australia Institute.

Fuhrer, R. (2020). *Modelling historical accessibility and its effects in space* (Doctoral dissertation). ETH Zurich.

Fulton, L. M., Noland, R. B., Meszler, D. J., & Thomas, J. (2000). A statistical analysis of induced travel effects in the US mid-Atlantic region.

Garcia-Lopez, M.-A. (2012). Urban spatial structure, suburbanization and transportation in Barcelona. *Journal of Urban Economics*, *72*(2-3), 176–190. https://doi.org/10.1016/J.JUE.2012.05.003

Gibbons, R. (1983). The 'fall of the giant': Trams versus trains versus buses in Sydney, 1900-61. In G. Wotherspoon (Ed.), *Sydney's Transport: Studies in Urban History* (pp. 155–176). Hale & Iremonger.

Google Developers. (2021). GTFS Static Reference [Accessed: 2021-12-22]. https://developers.google.com/transit/gtfs/reference

Granger, C. W. (1969). Investigating causal relations by econometric models and cross-spectral methods. *Econometrica: Journal of the Econometric Society*, 424–438.

Hakim, M. M., & Merkert, R. (2016). The causal relationship between air transport and economic growth: Empirical evidence from South Asia. *Journal of Transport Geography*, *56*, 120–127.

Hansen, M., & Huang, Y. (1997). Road supply and traffic in California urban areas. *Transportation Research Part A: Policy and Practice*, *31*(3), 205–218.

Hasan, M. A., Frame, D. J., Chapman, R., & Archie, K. M. (2019). Emissions from the road transport sector of New Zealand: Key drivers and challenges. *Environmental Science and Pollution Research*, 1–21.

Henderson, R. (2016). *Regional reviews by Ministry of Transport – 2006-2010* [Accessed: 2021-09-15]. http://sydneybusroutes.com/images/PDFs/regional%5C%20reviews.pdf

Henderson, R. (2021). Sydney bus routes: A history of private and government bus routes in Sydney [Accessed: 2021-07-14]. https://sydneybusroutes.com

Holland, P. W. (1986). Statistics and causal inference. *Journal of the American statistical Association*, *81*(396), 945–960.

Hounsell, M. (2019). NSW train stations. Barrier counts dashboard: 2004-2018. https://opendata.transport.nsw.gov.au/open-data-community-showcase

Hovenden, L. (1983). The impact of the motor vehicle, 1900-39. In G. Wotherspoon (Ed.), *Sydney's Transport: Studies in Urban History* (pp. 139–154). Hale & Iremonger.

Hu, Y., Xiao, J., Deng, Y., Xiao, Y., & Wang, S. (2015). Domestic air passenger traffic and economic growth in China: Evidence from heterogeneous panel models. *Journal of Air Transport Management*, *42*, 95–100. https://doi.org/10.1016/J.JAIRTRAMAN.2014.09.003

Iacono, M., & Levinson, D. (2016). Mutual causality in road network growth and economic development. *Transport Policy*, *45*, 209–217. https://doi.org/10.1016/J.TRANPOL.2015.06.005

Isik, C. (2012). The USA' s international travel demand and economic growth in Turkey : A causality analysis. *Tourismos: An International Multidisciplinary Journal of Tourism*, *7*(1), 235–252.

Jiwattanakulpaisarn, P., Noland, R. B., & Graham, D. J. (2010). Causal linkages between highways and sector-level employment. *Transportation Research Part A: Policy and Practice*, *44*(4), 265–280. https://doi.org/10.1016/J.TRA.2010.01.008

Jiwattanakulpaisarn, P., Noland, R. B., Graham, D. J., & Polak, J. W. (2009). Highway infrastructure and state-level employment: A causal spatial analysis. *Papers in Regional Science*, *88*(1), 133–159.

Kasraian, D., Maat, K., & van Wee, B. (2016). Development of rail infrastructure and its impact on urbanization in the Randstad, the Netherlands. *Journal of Transport and Land use*, *9*(1), 151–170.

Kasraian, D., Raghav, S., & Miller, E. J. (2020). A multi-decade longitudinal analysis of transportation and land use co-evolution in the Greater Toronto-Hamilton Area. *Journal of Transport Geography*, *84*, 102696.

Kayode, O., Babatunde, O., & Abiodun, F. (2013). An empirical analysis of transport infrastructure investment and economic growth in Nigeria. *Social science*, *2*(6), 179–188.

Keenan, D. R. (1979). *Tramways of Sydney*. Transit Press Sydney.

Kennedy, P. (2003). *A guide to econometrics*. MIT press.

King, D. (2011). Developing densely: Estimating the effect of subway growth on New York City land uses. *Journal of Transport and Land Use*, *4*(2), 19–32.

Kulendran, N., & Wilson, K. (2000). Is there a relationship between international trade and international travel? *Applied Economics*, *32*(8), 1001–1009. https://doi.org/10.1080/000368400322057

Kunama, N., Worapan, M., Phithakkitnukoon, S., & Demissie, M. (2017). GTFS-VIZ: Tool for preprocessing and visualizing GTFS data. *Proceedings of the 2017 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2017 ACM International Symposium on Wearable Computers*, 388–396.

Lahoorpoor, B. (2022). *Terraces, towers, trams, and trains : Examining the growth of Sydney using empirical models and agent-based simulation* (Doctoral dissertation). The University of Sydney.

Lahoorpoor, B., & Levinson, D. (2021). *An empirical model of land use and public transit co-developments in Sydney* (Working Paper No. 06). The University of Sydney.

Lean, H. H., Huang, W., & Hong, J. (2014). Logistics and economic development: Experience from China. *Transport Policy*, *32*, 96–104. https://doi.org/10.1016/J.TRANPOL.2014.01.003
Lennon, B., & Wotherspoon, G. (1983). Sydney's trams, 1861-1914: The rise of an urban mass transport system. In G. Wotherspoon (Ed.), *Sydney's Transport: Studies in Urban History* (pp. 101–114). Hale & Iremonger.
Levinson, D. (1995). An evolutionary transportation planning model: Structure and application. *Transportation Research Record*, *1493*, 64–73.
Levinson, D. (2008). Density and dispersion: The co-development of land use and rail in London. *Journal of Economic Geography*, *8*(1), 55–77.
Levinson, D., & Chen, W. (2005). Paving new ground: A Markov chain model of the change in transportation networks and land use. *Access to Destinations* (pp. 243–266). Emerald Group Publishing Limited. https://doi.org/10.1108/9780080460550-012
Levinson, D., & Karamalaputi, R. (2003). Induced supply: A model of highway network expansion at the microscopic level. *Journal of Transport Economics and Policy (JTEP)*, *37*(3), 297–318.
Levinson, D., & King, D. (2020). Transport access manual: A guide for measuring connection between people and places.
Levinson, D., Marshall, W., & Axhausen, K. (2017). *Elements of access: Transport planning for engineers, transport engineering for planners*. Network Design Lab.
Li, K., & Qi, G. (2016). Transport connectivity and regional development in China. *Journal of International Logistics and Trade*, *14*(2), 142–155.
Li, R., Wu, J., Liu, H., Gao, Z., Sun, H., Ding, R., & Tang, T. (2019). Crowded urban traffic: Co-evolution among land development, population, roads and vehicle ownership. *Nonlinear Dynamics*, *95*(4), 2783–2795.
Liddle, B. (2012). The systemic, long-run relation among gasoline demand, gasoline price, income, and vehicle ownership in OECD countries: Evidence from panel cointegration and causality modeling. *Transportation Research Part D: Transport and Environment*, *17*(4), 327–331.
Marazzo, M., Scherre, R., & Fernandes, E. (2010). Air transport demand and economic growth in Brazil: A time series analysis. *Transportation Research Part E: Logistics and Transportation Review*, *46*(2), 261–269. https://doi.org/10.1016/J.TRE.2009.08.008
McHugh, B. (2013). Pioneering open data standards: The GTFS story. *Beyond transparency: open data and the future of civic innovation*, 125–136.
Miller, E. J. (2018). Accessibility: Measurement and application in transportation planning. *Transport Reviews*, *38*(5), 551–555.
Mimeur, C., Queyroi, F., Banos, A., & Thévenin, T. (2018). Revisiting the structuring effect of transportation infrastructure: An empirical approach with the French Railway Network from 1860 to 1910. *Historical Methods: A Journal of Quantitative and Interdisciplinary History*, *51*(2), 65–81.

Moghaddam, D. K., & Maat, C. (2013). Interaction of rail infrastructure and urbanisation in the Netherlands; a preliminary analysis. *Colloquium Vervoersplanologisch Speurwerk 2013*, 1–16.
Möller, J., & Zierer, M. (2018). Autobahns and jobs: A regional study using historical instrumental variables. *Journal of Urban Economics*, *103*, 18–33. https://doi.org/10.1016/J.JUE.2017.10.002
moovit. (2022). Sydney Public Transit Statistics. https://moovitapp.com/insights/en/Moovit_Insights_Public_Transit_Index_Australia_Sydney-442
Mukkala, K., & Tervo, H. (2013). Air transportation and regional growth: Which way does the causality run? *Environment and Planning A*, *45*(6), 1508–1520.
Noland, R. B. (2001). Relationships between highway capacity and induced vehicle travel. *Transportation Research Part A: Policy and Practice*, *35*(1), 47–72.
Noland, R. B., & Cowart, W. A. (2000). Analysis of metropolitan highway capacity and the growth in vehicle miles of travel. *Transportation*, *27*(4), 363–390. https://doi.org/10.1023/A:1005288826997
NSW Government. (2013). Sydney's bus future. Simpler, faster, better bus service [Accessed: 2021-07-22]. https://mysydneycbd.nsw.gov.au/sites/default/files/user-files/uploads/bus-future-final-web.pdf
Open Data, Transport for NSW. (2021). Journey to Work (JTW) 1991. https://opendata.transport.nsw.gov.au/dataset/journey-work-jtw-1991
Open Mobility Data. (2021). Greater Sydney GTFS [Accessed: 2021-07-14]. https://transitfeeds.com/p/transport-for-nsw/237
OpenStreetMap contributors. (2021). Planet dump retrieved from https://planet.osm.org. https://www.openstreetmap.org
OpenTripPlanner. (2021). Multimodal Trip Planning [Accessed: 2021-07-22].
Owen, A., & Levinson, D. M. (2015). Modeling the commute mode share of transit using continuous accessibility to jobs. *Transportation research part A: policy and practice*, *74*, 110–122.
Pacheco, R. R., & Fernandes, E. (2017). International air passenger traffic, trade openness and exchange rate in Brazil: A Granger causality test. *Transportation Research Part A: Policy and Practice*, *101*, 22–29.
Parliament of New South Wales. (2022). Comprehensive index to all parliamentary documents available online. https://www.parliament.nsw.gov.au/hansard/Pages/Comprehensive-index-to-all-parliamentary-document.aspx
Pearl, J. (2009). *Causality*. Cambridge university press.
Pereira, R. H. M., Grégoire, L., Wessel, N., & Martins, J. (2019). Tutorial with reproducible example to estimate a travel time matrix using OpenTripPlanner and Python. https://github.com/rafapereirabr/otp-travel-time-matrix. doi:10.5281/zenodo.3242134
QGIS. (2021). Spatial Analysis (Interpolation). https://docs.qgis.org/3.22/en/docs/gentle_gis_introduction/spatial_analysis_interpolation.html#triangulated-irregular-network-tin
QGIS Development Team. (2021). *QGIS Geographic Information System*. QGIS Association. https://www.qgis.org

Ribeiro, J., Fontes, T., Soares, C., & Borges, J. L. (2021). Accessibility as an indicator to estimate social exclusion in public transport. *Transportation research procedia*, *52*, 740–747.

Sandell, R. (2021). UrbanFerryist [Tweet, 30 December 2021: A pictorial reminder that Sydney's ferry network of 1909 was very similar to what it is today - main change is the cessation of car ferries following the opening of the Harbour Bridge.]. https://twitter.com/UrbanFerryist/status/1476468691625594880

SATS. (1974). *Sydney Area Transportation Study. Volume 1. Base Year (1971) Data Report* (tech. rep.). Sydney, Ministry of Transport.

State Library New South Wales. (2022). Parliamentary papers. https://guides.sl.nsw.gov.au/government_legislation_and_publications_nsw/parliamentary_papers

Sydney Monorail. (2022). Sydney Monorail — Wikipedia, The Free Encyclopedia [Accessed: 29-09-2022]. https://en.wikipedia.org/wiki/Sydney_Monorail

Todeva, E. (2007). Network co-evolution.

Transport for New South Wales. (2022a). All modes historical patronage - Top Level Chart. https://www.transport.nsw.gov.au/data-and-research/passenger-travel/all-modes-patronage-historical/all-modes-historical-patronage

Transport for New South Wales. (2022b). Open Data. https://opendata.transport.nsw.gov.au

Transport for NSW. (2021). TfNSW Open Data Hub and Developer Portal [Accessed: 2021-07-14]. https://opendata.transport.nsw.gov.au

Transport for NSW. (2022). Metro [Accessed: 2022-09-29]. https://transportnsw.info/travel-info/ways-to-get-around/metro#/

Travers, G. (1982). *From city to suburb... a fifty year journey. The story of NSW government buses*. The Sydney Tramway Museum; The Historic Commercial Vehicle Association Co-op Ltd.

Tsui, W. H. K., & Fung, M. K. Y. (2016). Causality between business travel and trade volumes: Empirical evidence from Hong Kong. *Tourism Management*, *52*, 395–404. https://doi.org/10.1016/J.TOURMAN.2015.07.010

Van De Vijver, E. (2014). *Exploring the mutual relationship between air passenger transport and economic development: A quantitative study at various spatial scales* (Doctoral dissertation). Ghent University.

Vance, C., & Hedel, R. (2007). The impact of urban form on automobile travel: Disentangling causation from correlation. *Transportation*, *34*(5), 575–588. https://doi.org/10.1007/s11116-007-9128-6

Viguié, V., Liotta, C., Pfeiffer, B., & Coulombel, N. (2023). Can public transport improve accessibility for the poor over the long term? Empirical evidence in Paris, 1968–2010. *Journal of Transport Geography*, *106*, 103473.

Wachs, M., & Kumagai, T. G. (1973). Physical accessibility as a social indicator. *Socio-Economic Planning Sciences*, *7*(5), 437–456.

Wang, Y., Hao, C., & Liu, D. (2019). The spatial and temporal dimensions of the interdependence between the airline industry and the Chinese economy. *Journal of Transport Geography*, *74*, 201–210. https://doi.org/10.1016/J.JTRANGEO.2018.11.020

Wardrop, A. (2022). *A Tale of two systems: The evolution of Melbourne & Sydney's metropolitan railways from Federation to pre-pandemic*. https://arhsnsw.com.au/product/a-tale-of-two-systems-pre-order/

Wotherspoon, G. (2008). Sydney's Transport. *Sydney Journal*, *1*(1).

Wu, C., Jiang, Q., & Yang, H. (2018). Changes in cross-strait aviation policies and their impact on tourism flows since 2009. *Transport Policy*, *63*, 61–72. https://doi.org/10.1016/J.TRANPOL.2017.11.008

Wu, H., Levinson, D., & Owen, A. (2021). Commute mode share and access to jobs across US metropolitan areas. *Environment and Planning B: Urban Analytics and City Science*, *48*(4), 671–684.

Wu, J., Xu, M., & Gao, Z. (2014). Modeling the coevolution of road expansion and urban traffic growth. *Advances in Complex Systems*, *17*(01), 1450005.

Xie, F., & Levinson, D. (2010). How streetcars shaped suburbanization: A Granger causality analysis of land use and transit in the Twin Cities. *Journal of Economic Geography*, *10*(3), 453–470.

Zhang, L., & Levinson, D. (2017). A model of the rise and fall of roads. *Journal of Transport and Land Use*, *10*(1), 337–356. https://doi.org/10.5198/jtlu.2016.887

Zhang, L., Xu, W., & Li, M. (2009). Co-evolution of transportation and land use: Modeling historical dependencies in land use and transportation decision making. https://rosap.ntl.bts.gov/view/dot/18170