Traffic Jams in Japan: does public transit have an impact?

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Abstract

The mitigation of traffic congestion is a growing problem globally. We test whether there is a relationship between rail provision and road performance in Japan, using aggregate level data. Our motivation for examining Japan is the comparatively high level of rail provision in Japan. A regression analysis of prefectural data from 2010 finds that the length of rail has a significant effect on average road speed. This research finds a relationship in the data, but does not necessarily imply causation. A choice model at a smaller scale may give a better indication of whether the provision of rail directly mitigates traffic congestion.

Introduction

Traffic congestion is a decidedly negative impact of development and urbanization in many parts of the world. In Japan, congestion is perhaps an inevitable result of high levels of urban sprawl and population density. Congestion on roads has been a persistent problem in Japan. For instance, in 2010, the average speed on general roads[1] (excluding expressways) in the Tokyo metropolitan area was 15.7km/h, whereas the national average was 36.5km/h (Ministry of Land, Infrastructure, Transport and Tourism, 2009). Other urban areas, such as Osaka, and Nagoya, have similarly low average speeds.

Traffic congestion is undesirable because it increases the travel time required on roads, which reduces their efficiency as a mode of transport. There is a significant individual cost: drivers in the United States have a willingness to pay $8.00 to save an hour of driving time. The average driver in the United States experiences an annual cost pertaining to driving delay of $640 (Arnott 1994). The indirect costs of a congested road system may be even greater. Total factor productivity of a country may be affected if transport costs become high, and supply chains become disrupted by excessive travel times. Congestion also results in greater levels of air pollution: Barth (2009) finds that CO_2 emissions per mile are greatest for very low average speeds, which "generally represent stop-and-go driving".

[1] The term general roads (Ippan Douro) does not have a precise definition, but is generally accepted as meaning roads in Japan excluding expressways, toll roads, and private roads.

This is because idling, acceleration, and braking result in high levels of emissions, but shorter travel distances. This type of rationale is also likely to apply to other pollutants, such as NO_x compounds and particulates. In Japan, noise pollution is a significant issue; for instance, Kageyama et al. (1997) find that nighttime traffic volume of main roads may be a risk factor for insomnia in adult Japanese women. Therefore, traffic congestion has clear policy implications.

In economics parlance, congestion may be considered a consequence of the tragedy of the commons – users of roads derive a direct benefit from usage, but impose an external cost on other users and non-users. Consider a simple example: suppose there is a single road connecting two locations, with n users. The level of congestion on this road is directly proportional to the number of users, and therefore the cost of travel is:

$$T = a + bn \tag{1}$$

where a can be thought of as the time it takes to make the journey between the two locations when there is no traffic, and b is a coefficient term describing the marginal effect of a single user on the cost of travel. Therefore, the private cost of user n using the road is described by the function in (1). We denote the benefit that a user derives from reaching the destination at the end of the road by B_i. Thus, an additional user will join the road if $B_i \geq T$. Note that B_i tends to increase for each additional user. However, the additional user imposes a cost equal to b on the rest of the users. The additional user does not consider the cost imposed on the rest of the users. This is in spite of the fact that for some existing users, $B_i < T$. These users are significantly affected by the decision of the additional user. Because of the existence of this negative externality, traffic congestion will tend to be higher than is socially desired. Note that this simple framework does not include externalities to non-users, such as pollution.

We can develop this intuition further as follows. Suppose that there is a function of demand (D) for road use, that is a function of the costs of use, such as fuel and time. Suppose also that there is a function of supply (S) of road users that is a function of the quantity of users on the road (figure 1). The cost for drivers to use the road when there is no congestion is A. After a certain level of supply, the cost of use begins to increase because of congestion (B). The level of supply will increase until supply (S_1) is equal to demand and equilibrium is reached in the market. This gives a level of road use equal to Q_1. However, as elucidated previously, the costs of congestion do not accrue solely privately. They also increase the cost of use for other users, because they are a negative externality. Therefore, the social cost is described by S_2. S_2 intersects the demand curve at a lower level of road use than S_1, at Q_2. The problem here is that road users are only aware of the private cost, and so there is an oversupply of road users. The social optimum is lower, and so some type of intervention is required to reduce road usage to the appropriate level of Q_2.

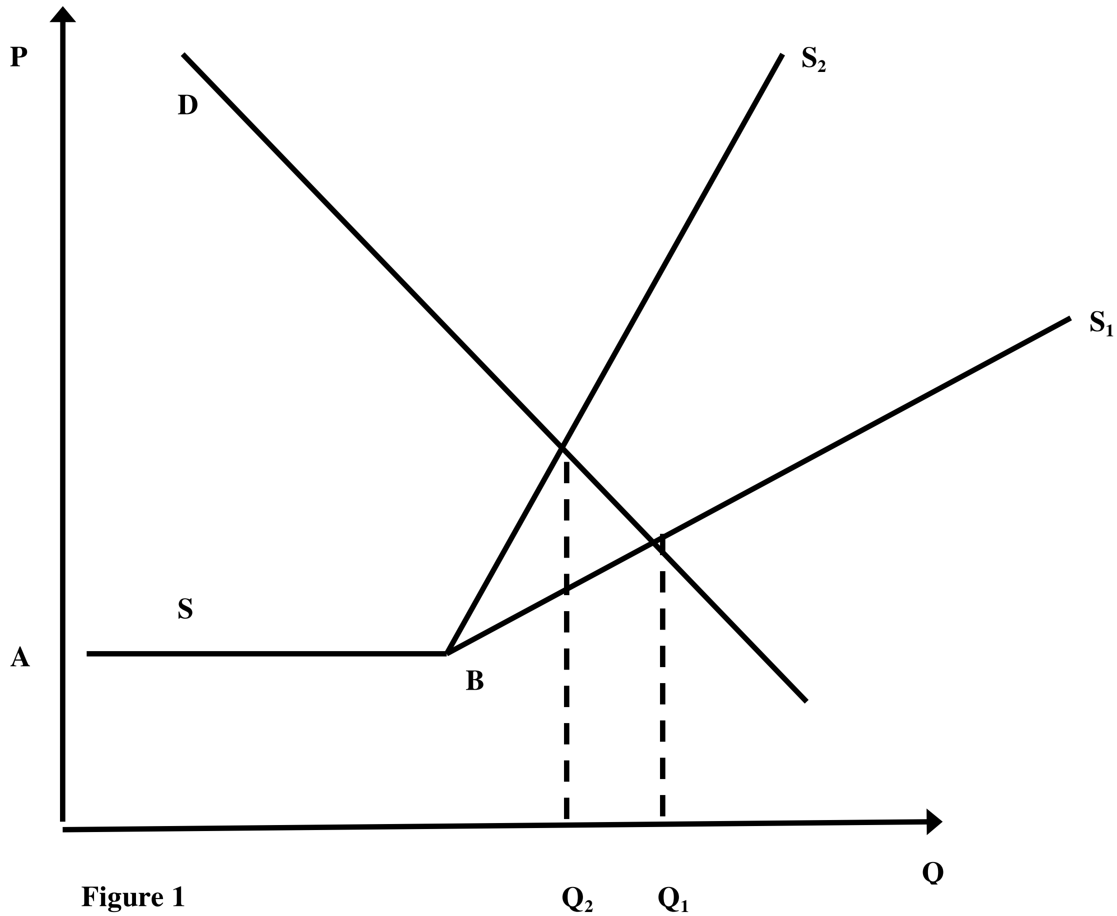

Figure 1

There are a few solutions that are apparent to the aforementioned problem of the tendency of roads to become congested. The first, classic solution to externalities is to internalize the externality. This involves charging users for usage of the road, so that their decisions are more likely to result in a socially acceptable level of congestion. For example, by charging additional users a cost equivalent to the cost borne by existing users when the additional user joins the road, the additional user is less likely to join the road if the level of congestion will become socially unacceptable. This was done with some success in London in 2003, with the introduction of the congestion charge, which charges vehicles in parts of Central London from

7:00 to 18:00 on weekdays. This approach may be considered beneficial in that it reduces congestion, and raises revenues for the government. However, this type of approach also reduces access to certain areas, and may have a negative effect on economic activity in these affected areas. Indeed, Leape (2006) comments that “the reductions in traffic and congestion met or exceeded predictions”. Furthermore, the average road speed in the congestion charge zone increased from an “all-day average” of 8.9mph to 10.4mph. However, he also notes that “the expected increase in rail trips did not materialize”, while “the rise in the number of individuals entering central London by bus exceeded predictions by almost 50 percent”. Also, the resource costs of running the congestion charge “have been twice as high as expected”. Bell et al. (2004) find a statistically significant negative impact of the congestion charge on sales in the congestion charge zone.

The second, rather intuitive approach is to increase the capacity of roads: doing so will surely reduce the density of traffic, and therefore reduce the amount of traffic congestion. Paradoxically however, expansion of road capacity may have the opposite effect in reality. Namely, an expansion in road capacity may *increase* the amount of congestion. There are several potential explanations for this in the literature (Arnott 1994), but here we focus on one. The *Downs-Thomson Paradox* states that the average travel time on roads is governed by the average travel time of an equivalent journey using another form of transport, such as rail. This relationship may exist because of the following rationale: suppose that roads and rail are equally utilized, and that they have equal travel times. Users will shift their usage if travel times are different. The government expands road capacity in the interest of making roads more efficient. This expansion in road capacity will temporarily increase the speed of road traffic, resulting in rail users shifting to road for the sake of shorter transport times. As a result, travel times on roads increase again because of greater congestion stemming from usage. Furthermore, rail revenues decrease because of lower rail traffic, causing a disinvestment in rail, and a reduction in the frequency of service: travel times on rail increase. Then, more rail users may shift to road, until the average travel time for each is equal. The new travel times will be longer than the initial travel times, and so the expansion in road capacity will have increased the usage of roads, and thus the amount of congestion. Empirically however, it is not entirely clear whether increasing road capacity increases, reduces, or has no effect on the level of congestion. Wood (2007) examines travel times for roads and public transit in several cities, finding that the *Downs-Thomson Paradox* does indeed appear to apply in reality. He concludes that reducing travel times on public transit is a solution to reducing congestion on roads. Duranton and Turner (2009) confirm a "fundamental law of road congestion", showing that increases in road capacity do not appear have any effect on the level of congestion in the United States. Furthermore, Hsu and Zhang (2014) use a similar approach to Duranton and Turner (2009), finding that the road elasticity of traffic is roughly one (implying that increases in road capacity do not have an effect on the level of congestion). They conclude that “building your way out of congestion is often fruitless”.

The third approach to reducing congestion on roads has been hinted in the previous discussion of the *Downs-Thomson Paradox.* Increasing the effectiveness of alternatives to road travel, such as rail, or bus travel, may result in an improvement in traffic congestion. The intuitive explanation is as follows: if there are effective alternatives to road travel, users on the margin are more likely to use alternatives, especially when their cost of usage is lower than that of road travel. In the framework of the *Downs-Thomson Paradox*, it is easy to see that an improvement in rail, resulting in lower travel times, is likely to result in lower travel times for road. This approach seems attractive: it does not impose a cost on users, and would appear to increase access, by providing more travel options to users.

Japan would appear to be a likely country in which this type of substitution effect may occur. It has a highly developed rail system that is well known for frequent, punctual departures. Although the total length of the rail network in Japan is similar to other comparable countries, such as Germany, 46 of the world’s 50 busiest stations are found in Japan. Hirooka (2000) notes the immense capacity of the rail system in Tokyo.

Previous research has not necessarily shown a clear relationship between the provision of rail and road congestion. Anderson (2013) utilizes the strike of transit workers in Los Angeles as a natural experiment to determine the effect of public transit on traffic congestion. He finds a significant congestion relief impact from transit provision. However, these results are derived from the entire transit system shutting down. In practice, marginal changes are of greater interest. Duranton and Turner (2009) find no evidence that the provision of public transport affects vehicle kilometers traveled. Recently, light rail has been introduced in many urban areas in an explicit attempt to reduce congestion and pollution. Semmens (2005) suggests that there is not a significant substitution effect between light rail and road travel. He finds that in the Phoenix region of Arizona, the impacts to congestion and air pollution of adding a light rail system to the street are minimal. However, Bhattacharjee and Goetz (2012) show that existing light rail in Denver have reduced congestions "within their influence zone", and imply that the introduction of the FasTracks system will reduce congestion "on the highways in its vicinity". The key appears to be that introducing greater rail capacity is clearly a costly undertaking; the benefits must also therefore be significant.

A difficulty in attempting to compellingly determine the relationship between rail travel and road transport is that there is not necessarily a consensus on the correct way of measuring traffic congestion. Bertini (2005) finds that there is not a consistent definition of congestion in a survey of "transportation professionals and academics". The most popular definitions pertain to time of travel, vehicle speed, and traffic volume. He notes the weakness of aggregate measures and that "we can no longer rely on the old way of system performance measurement." Although aggregate measures are not necessarily the ideal way of appraising congestion, the essence of this research makes it difficult to avoid such aggregate measures. This research touches on (and was inspired by) the *Downs-Thomson Paradox*. We are interested in the relationship between rail provision and the performance of road systems, and consider congestion to be a symptom of poor road system performance. Therefore, the focus of this research is to assess the performance of road systems, for which aggregate measures are perhaps more appropriate.

Measures of rail capacity are even more complicated. Although simple measures such as rail length, or number of stations may provide some insight into the provision of rail, capacity has many other determinants, such as the efficiency of the system, and type of rail cars. Indeed, estimating rail capacity is a significant undertaking, and is likely beyond the scope of this research.

The focus of this research is to determine whether effective rail transport has an effect on the incidence of traffic congestion. We posit that if the availability of alternative means of travel, such as rail, does have an effect on the level of traffic congestion, it is likely to occur in Japan, where the use of rail as an alternative to road is usually compelling.

Data

i. Cross-sectional

The general design of this research is to assess the relationship between road performance and the provision of rail in Japan. We do so in a few ways however. First, we examine cross-sectional data from all 47 prefectures in Japan to determine whether the level of rail provision in a prefecture has an effect on the level of road performance. This cross-sectional data is derived from a number of sources. The road traffic censuses of the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) are conducted roughly every three to five years. This census measures information regarding the national road network of Japan. Of interest in the census are the measurements of average weekday daytime traffic (AWDT), and average speed of roads. These variables are measured by dividing the roads into segments; data is taken from vehicles passing through the segment observation point. AWDT is measured from 7am to 7pm during a weekday. Average speed is measured during periods of congestion. The data itself therefore consists of hundreds of road segments with corresponding data. For this part of the research, we take aggregates to find the AWDT, and average speed of all roads within particular prefectures. Each prefecture is thus an individual observation point. Other data used for constructing the rest of the independent variables (which generally form the control variables) in the regression specification

Table 1. Summary statistics of the variables used in the cross-sectional part of the research. Dependent variables and independent variables of interest are bolded. Note that these data concern the 47 prefectures of Japan, taken in 2010. (Traffic Census = road traffic census; Annual Report = Annual Report on Regional Transport; Yearbook = Japan Statistical Yearbook)

Variable	n	μ	σ	Median	Min.	Max.	Source
Average road speed (km/h)	47	37.9	4.3	38.9	25.1	46.4	Traffic Census
AWDT (number of vehicles/km)	47	6278	3316	5184	2915	17080	Traffic Census
Rail length (km)	47	581.7	393.5	551.5	12.9	2567.0	Annual Report
Number of rail stations	47	204.6	148.5	158	15	778	Annual Report
Population density (persons/km^2)	47	5502	1619.5	4767	3417	11530	Yearbook
GDP per capita (¥ thousands)	47	2682	372.8	2657	2042	4369	Yearbook
Population owning a motor vehicle (%)	47	70.4	11.4	74.2	35.1	86.2	Yearbook
Population under the age of 14 (%)	47	14.2	1.0	14.2	11.0	18.5	Yearbook

are taken from the Japan Statistical Yearbook, and the Annual Report on Regional Transport[2]. The Japan Statistical Yearbook is published every year by the Statistics Bureau of the Ministry of Internal Affairs and Communications. It is a comprehensive summary of "basic statistical information of Japan covering wide-ranging fields such as Land, Population, Economy, Society, Culture, and so on". The Annual Report on Regional Transport is published every year by the Institution for Transport Policy Studies, and consists of statistics pertaining to various modes of transport on a prefectural basis. Note that all of these data concern the year 2010. Table 1 summarizes these data.

ii. Time series

We also examine time series data, but from the national perspective. The reason for this is logistical: only national data is publicly available for road traffic censuses before 2010. We hence take national level data from the road traffic censuses to find measures of road performance. The variable of interest is AWDT only here; there were not an adequate number of measurements for average speed.

We take the independent variables from other sources. The total length of rail is taken from the World Bank. We also find other information pertaining to rail provision from the Japan Statistical Yearbook. Finally, we

[2] Chiiki Koutsuu Nenpou, 2010 Edition, accessed at http://uub.jp

take data for control variables from the Japan Statistical Yearbook again, in the same vein as the cross-sectional analysis. Unlike the cross-sectional data, for which the number of observations was consistent, the time series data has varying levels of coverage for each variable. Therefore, the number of observations is not consistent, and this becomes a limiting factor for the number of observations in the regression analysis. These data are summarized in table 2. Generally, we attempted to match data to the data from the road traffic censuses, from 1962 to 2010; unfortunately however this results in a very low number of potential observations.

Table 2. Summary of the data used in the time series part of the research. Dependent variables and independent variables of interest are bolded. Observations are from the national level, taken from 1962 to 2010. (Traffic Census = road traffic census; Yearbook = Japan Statistical Yearbook)

Variable	n	μ	σ	Median	Min.	Max.	Source
AWDT (number of vehicles/km)	16	4195	1606	4262	1098	6088	Traffic Census
Rail length (km)	10	21130	1232.7	20590	20040	23300	World Bank
Number of rail stations	14	10180	780.3	9886	9466	11860	Yearbook
Rolling stock	14	128700	55019.8	134600	65000	196000	Yearbook
Population (thousands)	16	116500	10991.9	2657	2042	4369	Yearbook
GDP per capita (¥ hundreds, current prices)	14	21470	13899.8	22040	2305	40400	Yearbook
Population owning a motor vehicle (%)	15	35.6	19.1	37.3	5.2	61.3	Yearbook
Population under the age of 14 (%)	16	20.6	4.8	22.0	13.3	28.7	Yearbook

Methodology

i. Cross-sectional

The first part of this research consists of a cross-sectional model of various prefectural characteristics taken from 2010. The available data consists of variables that were chosen to measure road performance, and potential control variables (Table 1). The regression specification is as follows:

$$Y_i = \gamma R_i + \beta X_i' + \varepsilon_i \tag{2}$$

where Y_i is the measure of road performance for each prefecture, R_i is the measure of rail provision for each prefecture, X_i is a row vector of control variables, and ε_i is the error term. Therefore, γ is the parameter of interest: the effect of rail provision on road performance. The control variables are added to the regression specification in an attempt to reduce the effect of omitted variable bias on γ. It is not clear which of AWDT or average road speed is the appropriate dependent variable in (2); indeed both are suitable aggregate measures of road performance. However, AWDT may share covariate factors with rail provision, relating to development. Nonetheless, we select the best variable using feature selection. In particular, we employ best subsets selection, with the Bayesian Information Criterion (BIC) as the selection parameter. This involves fitting all possible permutations of variables, and selecting the model with the highest BIC value. Doing so will select a model that is most likely to reflect the data.

ii. Time series

The second part of this research consists of a time series model of national characteristics from 1962 to 2010. The regression specification is:

$$Y_t = \gamma R_t + \beta X_t' + \varepsilon_t \tag{3}$$

where Y_t is the measure of road performance for each year, R_t is the measure of rail provision for each year, X_t is a row vector of control variables, and ε_t is the error term. Note that unlike the cross-sectional regression, the potential variables for Y_t are AWDT and the congestion level, calculated by the MLIT. Different specifications of this model have different numbers of observations, because of varying levels of coverage for the different variables obtained. Again, I select the best features here using best subsets selection.

Results

i. Cross-sectional

Table 3. Estimates for the effect of rail length on average speed and AWDT are statistically significant across all regression specifications.

Dependent variable: Average speed; AWDT in II	I	II	III	IV
Intercept	60.91*** (9.53)	-1.57e+04* (7.30e+03)	44.40*** (1.65)	42.87*** (1.69)
Rail length, km	**0.0062*** (0.0016)**	**-1.94e+00 (1.25e+00)**	**0.0071*** (0.0015)**	**0.0089*** (0.0021)**
Number of rail stations	**-0.02* (0.0064)**	**9.62e+00 (4.93e+00)**	**-0.018** (0.0054)**	**-0.024*** (0.0056)**
Population density, persons per km^2	-0.00099 (0.00062)	7.88e-01 (4.77e-01)	-0.0013*** (0.00034)	-0.00090* (0,00035)
GDP per capita (¥ thousands)	-0.0023 (0.0014)	2.71e+00* (1.04e+00)		
Car ownership, %	0.041 (0.088)	-3.52e+01 (6.73e+01)		
Population under 14 years old, %	-1.028* (0.47)	8.49e+02* (3.61e+02)		
Adjusted R^2	0.73	0.74	0.71	0.72
Number of observations	47	47	47	45

*Note: Significance levels *p<5% **p<1%, ***p<0.1%. Standard errors in parentheses*

Table 3 shows the results of the cross-sectional regression. Regression I corresponds to a linear regression of all variables on the average speed of roads in each prefecture, while regression II regresses all variables on the AWDT of roads in each prefecture. Regression III is the model that is chosen by best subsets selection, while regression IV improves on regression III by removing potential outliers. The outliers were removed by observing Cook's distance for each of the observations, which is an estimate of the influence of observations on the regression plane. Cook's distance is calculated as follows:

$$D_i = \frac{\sum_{j=1}^{n}(\widehat{Y_j} - \widehat{Y_{j(i)}})^2}{p\ MSE} \tag{4}$$

where $\widehat{Y_j}$ is the predicted value for observation j from the full model and $\widehat{Y_{j(i)}}$ is the predicted value for observation j from a reduced model in which observation i has been removed. p is the number of parameters in the model, and MSE refers to the mean square error of the model. Observing Cook's distance for the observations in specification III found a couple of influential observations (figure 2). These are labeled on the graph; interestingly, they

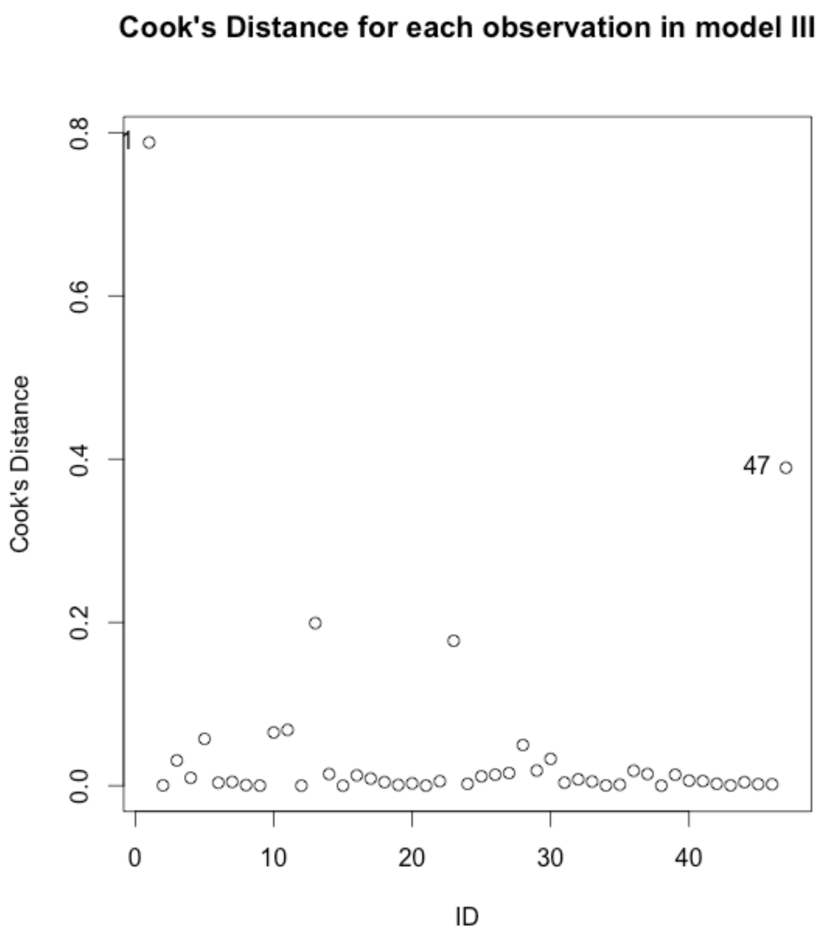

Figure 2

correspond to Hokkaido, and Okinawa prefectures, which are respectively the northernmost and southernmost prefectures in Japan (figure 3). These prefectures are likely to have characteristics that are different to those of the remaining prefectures, implying that these prefectures diverge from the rest of the prefectures within the context of this model. The implication here is that there may have been omitted variables in the model, which may have

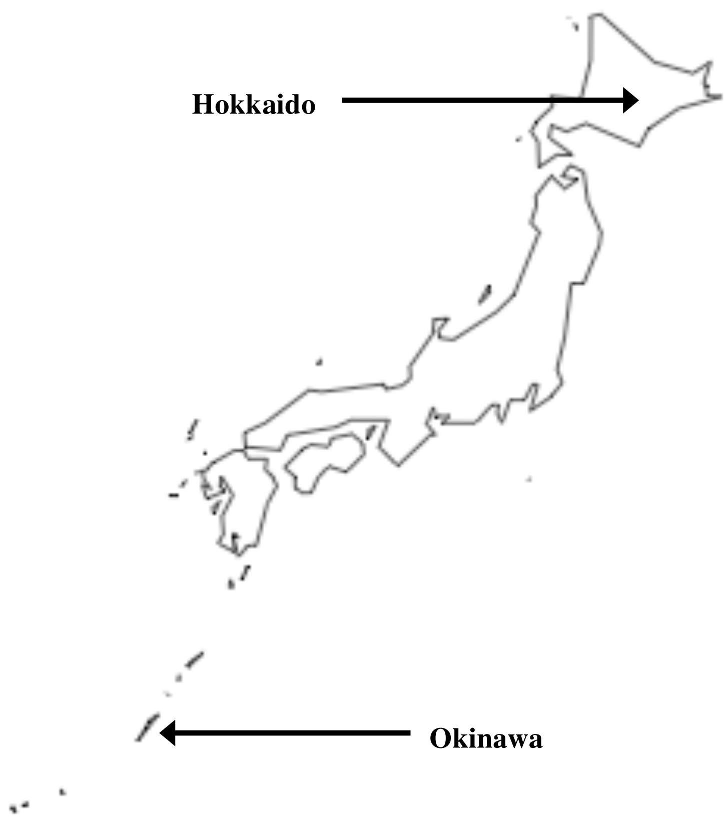

Figure 3

captured the variation inherent in these regions that may not be homogeneous with respect to the rest of Japan. Indeed, when these potential outliers are removed in specification IV, the fit of the model to the data becomes somewhat better.

The control variables were selected based on reasoning; these were variables that were thought to influence the level of road performance. However, it is clear that many of them do not appear to have significant explanatory power, and indeed, best subsets selection removed all but one of the variables, population density. For specification II, it is apparent that most of the variables appear to have little explanatory power. This perhaps confirms the notion that AWDT is not an appropriate measure of road performance, perhaps because it shares covariates pertaining to development with rail provision.

Although rail length appears to have a positive effect on average road speed, it is apparent that the number of rail stations appears to have a negative effect on average road speed. This is confounding since these two variables were intended to measure the same factor, namely rail provision. One may speculate reasons for this, such as the development of stations developing greater levels of traffic, because of the tendency for private rail companies in Japan to engage in large retail businesses around the location of rail stations (Nakamura, 1995). However, it must be said that this result does not definitively show that rail provision helps alleviate congestion and improve road performance.

To better understand these effects, we employ a regression model that is based on that of specification IV, but with an interaction term. Table 4 depicts the results of this regression.

Table 4. Estimate for the effect of rail length on average road speed is statistically significant, but the interaction term is not statistically significant, implying independence of the effects.

Dependent variable: Average road speed	V
Intercept	4.45e+01*** (2.067e+00)
Rail length, km	**7.40e-03** (2.34e-03)**
Number of rail stations	**-4.03e-02** (1.29e-02)**
Population density, persons per km^2	-8.77e-04 (3.47e-04)
Rail length x Number of rail stations	1.63e-05 (1.19e-05)
Adjusted R^2	0.72
Number of observations	45

*Note: Significance levels *p<5% **p<1%, ***p<0.1%. Standard errors in parentheses*

Specification V implies that there is no interaction effect between rail length and number of rail stations. Hence, the effects work independently, and so we conclude with our earlier finding: average road speed appears to increase with rail length, while it appears to decrease with the number of rail stations.

Referring back to IV, we can say that the marginal effect of an increase in rail length on average road speed is:

$$\frac{\partial Y}{\partial R} = \gamma \tag{3}$$

where Y is the average road speed, R is the rail length and γ is the regression coefficient for road length in specification IV. Therefore, the marginal effect of an increase in rail length on road speed is 0.0089 km/h/km. Similarly, the marginal effect of an additional rail station on road speed is -0.024 km/h/km.

ii. Time series

Table 5. Estimates of the effect of the number of rail stations and rolling stock on AWDT are statistically significant.

Dependent variable: AWDT	I	II
Intercept	3.96e+02 (5.85e+03)	6.62e+03*** (1.13e+03)
Number of rail stations	**-9.62e-02** **(1.80e-01)**	**-2.83e-01***** **(4.95e-02)**
Rolling stock	**4.45e-03*** **(1.76e-03)**	**3.58e-03**** **(1.08e-03)**
Population density, persons per km^2	-3.80e-02 (3.50e-02)	
GDP per capita (¥ thousands)	-1.60e-02 (2.29e-02)	
Car ownership, %	6.17e+01** (1.20e+01)	6.18e+01*** (6.96e+00)
Population under 14 years old, %	-1.00e+02** (2.02e+01)	-1.09e+02*** (1.722e+01)
Adjusted R^2	0.998	0.999
Number of observations	13	13

*Note: Significance levels *p<5% **p<1%, ***p<0.1%. Standard errors in parentheses*

The regression results of the time series data are shown in table 5. Here, specification I includes all variables, while specification II includes only those variables that were selected by best subsets selection. It is apparent that specification II certainly appears to perform better than specification I, while being more parsimonious. All of the variables in specification II are significant. Again, as in the cross-sectional model, our measures of rail provision seem to give contradictory results. The level of rolling stock seems to have a positive effect on AWDT, while the number of rail stations appears to have a negative effect on AWDT. Again, we may speculate that greater levels of rolling stock increase the efficiency of rail, making it more attractive as an alternative, increasing the performance of roads, while greater numbers of stations increases road traffic to the stations, creating congestion and reducing road performance. However, we should be wary of the external validity of these estimates, given the very low number of observations.

Conclusion

This research attempts to examine whether the provision of rail has an effect on road performance in Japan. The rationale of this argument derives from the *Downs-Thomson Paradox*, which suggests that the speed of road travel and rail travel tend to a certain equilibrium. Hence, increasing the speed (or efficiency) of rail travel is likely to increase the speed of road travel. We use aggregate level data to determine the relationship between provision of rail and road performance. We do so from both the cross-sectional (prefectural) and time series (national) perspectives by ordinary least squares linear regression. We select variables by using best subsets selection, with the BIC as the selection criterion.

Although both regressions lead to models that appear to have a reasonable level of explanatory power, the cross-sectional regression has more credence because of its higher sample size. We find that the length of rail does appear to have an ameliorating effect on road performance, measured by average road speed. However, the number of rail stations appears to have a harmful effect on road performance, reducing average road speed. We speculate that this may be because of the tendency for retail and residential businesses to develop around rail stations, increasing road traffic regionally. Nonetheless, we estimate that the marginal effect of an increase in rail length on road speed is 0.0089km/h/km.

There are certainly a number of limitations and potential areas for further investigation. First, Japan has a highly developed rail network, and standard measures of rail provision, such as railroad length, number of stations, and rolling stock, may not adequately reflect the efficiency of the Japanese rail system. Although this research does find potential evidence for rail having an effect on road performance, it underlines the notion that aggregate level data may not be appropriate in answering this question. The aggregate level data does not elucidate the internal dynamics of decisions to choose alternative modes of transport to road.

Second, we may be able to gain a better understanding of this potential phenomenon by finding more accurate, and suitable measures of road performance. For instance, the use of aggregate road speed in this research does not take into account the type of road, or user characteristics. A more accurate picture of decisions on the margin (between choosing different modes of transport) may be gained by considering these characteristics.

Also, an extension of this research would involve prefectural data from the road traffic censuses prior to 2010. Doing so would enable a panel data study, and potentially a fixed effects (time invariant effects) model which would allow much more accurate isolation of the effects of interest.

Finally, the aggregate approach in this research may not be the most accurate way of modeling what is likely a complex relationship between rail and road. Choice models, such as those in Anderson (2013) may give a better indication of the extent to which individual users do substitute between road and rail. A more small-scale analysis, such as that done by Bhattacharjee and Goetz (2012) may also give a better indication of these substitution decisions. An extension of this research may be to examine the Tokyo Metropolitan Area alone, with richer, smaller-scale data.

References

Anderson, M.L. (2013), "Subways, Strikes, and Slowdowns: The Impacts of Public Transit on Traffic Congestion", *American Economic Review*, 104(9), 2763-96

Bhattacharjee and Goetz (2012), "Impact of light rail on traffic congestion in Devner", *Journal of Transport Geography*, 22, 262-270

Arnott, R. and Small, K. (1994), "The Economics of Traffic Congestion", *American Scientist*, 82(5), 446-455

Barth, M. and Boriboonsomsin, K. (2009), "Traffic Congestion and Greenhouse Gases", *Access*, 35, 2-9

Bertini, R.L. (2005), "You Are the Traffic Jam: An Examination of Congestion Measures", *85th Annual Meeting for the Transportation Research Board*

Duranton, G. and Turner, M. A. (2011), "The Fundamental Law of Road Congestion: Evidence from US cities", *American Economic Review*, 101(6), 2616-52

Hirooka, H. (2000), "The Development of Tokyo's Rail Network", *Japan Railway and Transport Review*, 23, 22-31

Hsu, W-T. and Zhang, H. (2014), "The fundamental law of highway congestion revisited: Evidence from national expressways in Japan", *Journal of Urban Economics*, 81, 65-76

Nakamura, H. (1995), "Transportation Problems in Tokyo", *Japan Railway & Transport Review*, March 1995, 2-7

Kageyama, T., Kabuto, M., Nitta, H., Kurokawa, Y., Taira, K., Suzuki, S., and Takemoto, T. (1997), "A population study on risk factors for insomnia among adult Japanese women: a possible effect of road traffic volume", *Sleep*, 20(11), 963-971

Leape, J. (2006), "The London Congestion Charge", *The Journal of Economic Perspectives*, 20(4), 157-176

Ministry of Land, Infrastructure, Tourism, and Transport (2009), Road Traffic Census

Semmens, J. (2005), "Does Light Rail Worsen Congestion & Air Quality?", *Transport Research Board,* 84th Annual Meeting

Wood, K. (2007), "The Paradox of Congestion", *IPENZ Transportation Group Conference*