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Does Public Transit reduce Car Travel Externalities?

Martin W. Adler
Jos N. van Ommeren

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Quasi-natural experiments' evidence from transit strikes

Discussion Paper

Martin W. Adler and Jos N. van Ommeren

VU University Amsterdam and Tinbergen Institute

January 20 2015

Abstract

One of the main unanswered questions in the field of urban economics is to which extent subsidies to public transit are justified. We examine one of the main benefits of public transit, a reduction in car congestion externalities, the so-called congestion relief benefit, using quasi-natural experimental data on citywide public transit strikes for Rotterdam. On weekdays, a strike induces car speed to decrease only marginally on the highway ring road (by 3 percent) but substantially on inner city roads (by 10 percent). During rush hour, the strike effect is much more pronounced. The congestion relief benefit is substantial, equivalent to about half of the public transit subsidy. We demonstrate that during weekends, car speed does not change noticeable due to strikes. Further, we show that public transit strikes induce similar increases in number of cyclists as number of car travelers suggesting that bicycling-promoting policies to reduce car congestion externalities might be attractive.

Keywords: transit subsidies, public transit, traffic congestion, congestion relief benefit, strike

JEL H76, J52, L92, R41

1. Introduction

The provision of public transit is thought to reduce travel time losses that are due to car congestion. For this reason, it is economically justified to subsidise public transit from a welfare perspective as it creates a congestion-relief benefit.[1] Note that car use and public transit use are not perfect substitutes, so subsidies to public transit provision might be interpreted as a second-best policy. It is then important to realise that public transit provision is not the only policy alternative for policymakers to address negative car externalities (Basso and Silva, 2014). For example, we will provide evidence that bicycling-promoting policies might be another cost-effective way to realise congestion-relief benefits.

The main goal of this paper is to quantify the congestion-relief benefit of public transit for Rotterdam by analysing car speed during public transit strikes.[2] Arguably, strikes can be interpreted as exogenous transit supply shocks and therefore as a quasi-natural experiment as argued by a series of studies (Crain and Flynn, 1975; Van Exel and Rietveld, 2001; Aftabuzzaman et al., 2010; Marsden and Docherty, 2013).[3] We are aware of two other papers that use the same methodology. Lo and Hall (2006) and, more recently, Anderson (2014) both analyse the effect of (the same) *single* transit strike lasting 35 days on highway speed for Los Angeles. Anderson (2014) finds a substantial congestion relief benefit with a decrease in time delays experienced by car drivers of 0.12 minutes per kilometer traveled. [4] It is unknown to what extent this result can be generalised to cities where the share of public transit use is much higher or to cities where bicycle use might be a viable alternative.[5]

Our analysis differs from Anderson (2014) and Lo and Hall (2006) in a number of ways. First, we focus on a city, Rotterdam in the Netherlands, which, as we will document, is only mildly congested. Second, we analyse the effect of *multiple* strikes of *various* public

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[1] The other main reasons for public transit provision are that car travel is underpriced and that public transit's average costs are lower than its marginal costs because of the presence of fixed cost and the 'Mohring (1972) effect'. Car congestion is the main externality of car travel in addition to air pollution and road accidents.

[2] Up to the 90´s, strikes received a lot of attention in the economics literature which shows that the majority of strike days are public sector strikes. For example, 86% of UK strike days are in this sector (ONS, 2014). In many countries, a large share of public sector strikes are public transit firms, because these firms have market power, and are unionized, which are both key strike determinants.

[3] Information about the congestion-relief benefit of public transit is essential for a welfare analysis of public transit provision such as the study by Parry and Small (2009) which assumes that public transit provision reduces car travel time by 0.04 minutes per kilometer traveled, substantially less than the results indicated by Anderson (2014). Nevertheless, similar to Nelson et. al (2007), they conclude that subsidies up to 90% of operating cost would be welfare improving. Also Proost and Van Dender (2008) and Basso and Silva (2014) indicate that during peak hours, it would be beneficial if subsidies cover 50% up to 100% of operating cost.

[4] Lo and Hall (2006) report speed reductions by 20% to 40%. However, an earlier strike in the year 2000, not analysed by Lo and Hall (2006) and Anderson (2014) seems to decrease speed by only 5% (The Economist, 2000).

[5] As is well known, in comparison to Los Angeles, almost all European and Asian cities provide levels of public transit that are an order of magnitude higher. Because it is likely that the congestion relief benefit is a concave function of the level of transit provision, the marginal benefit might be lower in these cities.

transit modes (e.g. bus, light rail) that are *citywide*. Third, we examine the strike effect on car speed (and flow) both for the highway ring road as well as within the inner-city of Rotterdam. Fourth, we examine to what extent transit strikes induce public transit travelers to switch into cycling. The latter is particularly relevant, because, as argued by Basso and Silva (2014), public transit subsidies should be evaluated according to other urban policies with a similar aim, such as congestion pricing and bicycling-promoting policies. Finally, by examining heterogeneity in the effects of strikes, we are able to improve our understanding when the public transit relief benefit is particularly pronounced. For example, as one may expect, we find a particularly strong effect of strikes on car speed during weekday rush hours (but no clear effect during weekends and outside rush hours). In addition, our results suggest that the speed effects of strikes that last a few hours are similar to full-day strikes indicating that a continuous supply of public transit during the day is essential for travelers.

We show that the congestion relief impact in Rotterdam is by a factor ten larger for inner city roads than for highway ring roads. For the latter we found a several times smaller effect than Anderson (2014). It turns out that the congestion relief benefit of public transit for Rotterdam is substantial, and about 50% of the current subsidy level. This result is particularly noteworthy as we focus on what can be considered an uncongested city. This suggests that subsidies to public transit are welfare improving, even for cities that exhibit low congestion levels.

2. Data and descriptives

2.1 Introduction

We analyse public transit strikes for the period 2001 to 2011 for Rotterdam, a Dutch city with a metropolitan population of about 1.2 million inhabitants. Public transit use is substantial: 21% of residents and 25% of commuters use it each day. Car ownership is low: only 57% of adults belong to a car-owning household, but the proportion of commuters who travel by car is representative for the Netherlands: about half of the Rotterdam commuters travel by car (De Vries, 2013). Average speed for a commuter car trip is about 30km/h (Savelberg, 2013). As will be documented later on, in Rotterdam there is little car congestion, as speed within the city, as well as on the highway ring road is close to the legal maximum speed limit. Also, as is well known, in the Netherlands, the use of the bicycle is quite common. In line with this, the large majority of Rotterdam residents own a bicycle. We emphasise however that bicycle use

is low from a Dutch perspective: only 14 percent of commuters use it on a daily basis (by comparison, in Amsterdam this percentage is more than double). [6]

There is one public transit operator RET which provides non-regional bus, tram, metro and light rail connections within the Rotterdam metropolitan area. Regional bus connections are provided by another (private) company. [7] Within Rotterdam, many roads have separate bicycle paths, which allows us to measure bicycle use.

We will analyse hourly information about bicycle flow, car flow and car speed for the inner city and about car flow and car speed for the highway ring road (see subsections 2.3 and 2.4) and relate this to the occurrence of strikes (see subsection 2.2). [8]

2.2 Strikes

Information on public transit strikes is obtained from the Rotterdam municipality, the public transit operator, newspapers and Internet search. We observe 16 public transit strikes between 2001 and 2011. Table 1 lists these strikes by mode, type, date, time and additional information, such as whether the strikes were announced. We focus on 13 *citywide* transit strikes, defined as strikes that affect all non-regional buses, trams and metro within the city, but also consider two national rail strikes and one regional bus strike. [9] Regional buses also operate on routes inside the city, but during citywide strikes do not stop within the city (in order not to break the strike).

About half of the citywide strikes last a full day. The other half usually ends after four to five hours, and will be labeled partial-day strikes. The majority of strikes include rush hours, defined to be between 7am-9am and 4pm-6pm *on weekdays*. All strikes end within 24 hours after commencement except for one regional bus strike that involves strike disruptions on three consecutive days within Rotterdam. For only one strike (in October 2014), both national rail and citywide transit strikes occurred on the same day. Importantly, all strikes, except two, were announced (also in national media) well in advance. [10]

Three strikes were first announced and later canceled. We will use these canceled strikes as placebo strikes. Arguably, if the effect of announcements of strikes on switching

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[6] One of the reasons for the low bicycle use in Rotterdam is that it has been rebuilt as a modern ('American') city after its destruction during the Second World War.

[7] Rail is supplied by semi-public rail operator, and regional bus is supplied by a private firm Connexxion.

[8] Information on inner city traffic is provided by Rotterdam municipality and on highway traffic by TNO.

[9] About one third of Dutch train users combine train use with bicycle or car use (van Goeverden and Egeter, 1993, and van der Loop, 1997), so a train strike may decrease bicycle and car use for some train travellers.

[10] Strike information prior to the strike is not always clear and sometimes even misleading. For example, for the 12th of April 2011 strike, travelers were warned that services would be gradually reduced starting from 9am but actually service provision grinded to a complete halt at this time (Treinreiziger, 2011).

travel mode is sufficiently small (for which we will provide evidence), then these canceled strikes can indeed be interpreted as placebo strikes. [11]

Table 1 – Public transit strikes Rotterdam, 2000-2011

Type	Date		Time	Information
Citywide strikes				
	Wednesday	08-10-2003	10am to 2pm	
	Thursday	14-10-2004	Full-day	Also rail
	Wednesday	29-06-2005	Full-day	
	Monday	04-09-2006	12am to 1pm	No metro strike, unannounced
	Monday	18-09-2006	8am to 1pm	Unannounced
	Monday	25-09-2006	Full-day	
	Wednesday	15-11-2006	10am to 4pm	No metro strike
	Wednesday	16-02-2011	Full-day	Reduced schedule
	Tuesday	12-04-2011	9am to 2pm	
	Wednesday	11-05-2011	5am - 9am	Irregular schedule
	Thursday	09-06-2011	Full-day	
	Wednesday	29-06-2011	9am to 3pm	
	Sunday	20-11-2011	Full-day	
Rail strikes (only)				
	Thursday	21-12-2000	Full-day	
	Friday	17-06-2005	Full-day	
Regional bus strike (only)				
	Tuesday	20-05-2008	} 9am to 4pm, after 7pm	
	Wednesday	21-05-2008		
	Thursday	22-05-2008		
Placebo strikes				
Rail strike	Monday	02-04-2001	No strike	Canceled
Citywide strike	Wednesday	06-10-2009	No strike	Canceled
Citywide strike	Sunday	06-11-2011	No strike	Canceled

2.3 Inner City Traffic

For the inner city, information on the hourly number of cars on the road and bicycle travelers on bicycle paths is collected by pneumatic tubes. We have this information for all directions at 24 locations, equally distributed over the city (see Figure A1 in the Appendix).[12] For 21 out of 24 locations, there is information on either car or bicycle travel. For three locations, two bridges and a tunnel that span the river Maas, information on both car and bicycle travel is available.[13] In total, we have 36 measurement directions for bicycle flow on bicycle paths and

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[11] Cancellations occur due to legal challenges and not due to anticipated road conditions. The placebo strike in 2011 was canceled a week before, but the other two only hours before. Because we will show that announced and unannounced strikes have similar effects, it is reasonable to interpret canceled strikes as placebo strikes.

[12] Most locations have two directions. There are is one location with information on one direction and one location with three directions.

[13] The river Maas is a major waterway that divides the city into two parts. The two bridges and tunnel are the only possibility to cross within a span of 5km.

16 for car flow (see Table A1 in Appendix).[14] For two locations, so four directions, we have information on car travel speed. Although we have only four independent speed measurements, these can be thought to be representative for the speed within the whole city as previous studies indicate that within-city speed observations over different locations are strongly correlated (e.g. Arnott, 2013; Fosgerau and Small, 2013).

Figure 1 – Car speed
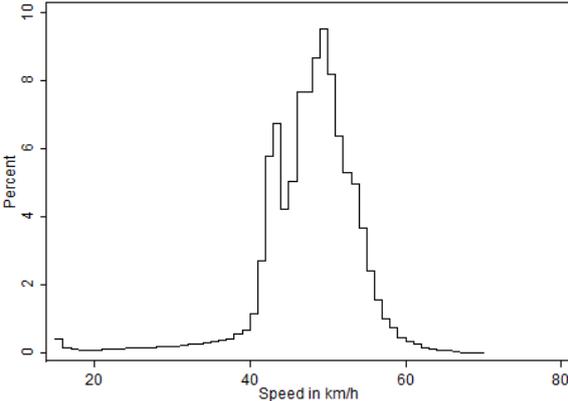
Figure 2 – Car and Bicycle flows
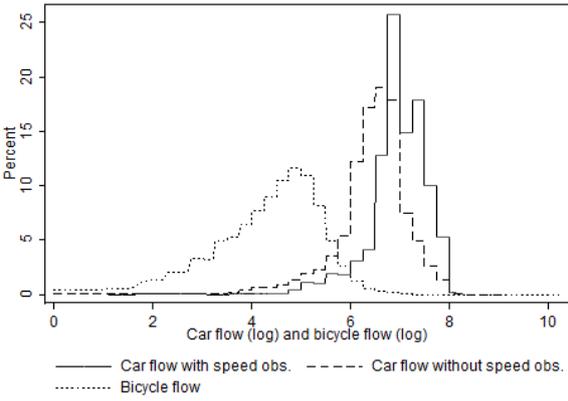
In our analysis, for a causal interpretation of the strike effect, we aim to compare transport outcomes on strike days with transport outcomes on similar non-strike days. As can been seen in Table 1, during certain periods (e.g. the summer) there were no strikes. Although this may be accidental, it is also possible that strikes were avoided during certain periods for certain reason (e.g. during the summer public transit use is lower, so a strike may be less or more desirable from the point of view of the strike organizer). Hence, we exclude four months (January, March, July and August) and three years without a strike (2002, 2007 and 2010).[15] Car flow is for a few observations zero and for convenience (as we will use logs) these observations will be excluded. We focus on observations between 6am and 8pm (i.e. 14 hours). In total, we have 88,106 hourly observations of car speed, 338,782 of car flow and 719,661 of bicycle flow.

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[14] Cycling paths are separated traffic lanes designated for bicycle travel. For most paths this includes a small share of motorized bicycles and small scooters. Negative measurement error for bicycle flow is present because only one bicycle can be recorded every 0.050 seconds. This results in downward bias of 5% to 20% for highly frequented paths (Bell and Vibbert, 1990). Hence, our estimates of strike effects on bicycle travel may be somewhat biased towards zero.

[15] Including these observations provides almost identical results. About 12.2% of observations are missing, as, due to malfunction and vandalism pneumatic tubes are occasionally not operating. The occurrence of missing observations is independent of the occurrence of strikes and missing observations are excluded from the analysis without introducing selection bias.

Our measure of car speed is based on the proportion of vehicles that travel at a certain speed (during one hour), observed for 11 speed intervals.[16] We construct hourly speed by calculating the average using the mid-speed value and the proportion of cars per interval.[17] This is potentially problematic, because the lowest interval, below 31 kilometer per hour (km/h), is quite large. For this speed interval, we assume cars to drive 15km/h, but we also make other assumptions as discussed in the sensitivity analyses. Car speed is (almost) normally distributed, see Figure 1, and locations with information on car speed have a similar car flow distribution as other locations, see Figure 2.

Table 3a – Summary statistics inner city traffic

	Car speed			Car flow			Bicycle flow		
	Mean	SD	Obs.	Mean	SD	Obs.	Mean	SD	Obs.
Full-day citywide strike	44.5	8.8	294	894.1	508.7	854	188.1	249.6	2,212
Rush hour	39.7	10.7	68	1,090.0	568.7	212	312.4	234.8	506
Non-rush hour	46.0	7.6	226	829.3	470.1	642	151.6	242.1	1,702
Partial-day citywide strike	45.3	7.3	348	911.0	514.9	992	179.5	163.3	2,605
Strike & rush hour	37.1	9.9	12	1165.6	664.5	28	359.6	251.5	83
Strike & non-rush hour	47.6	3.9	94	864.6	426.8	270	146.6	128.6	727
Non-strike & rush hour	42.0	9.5	88	1,060.5	615.7	256	241.9	188.8	664
Non-strike & non-rush hour	46.9	6.2	154	835.9	903.1	438	151.3	138.1	1,127
Rail strike	45.9	4.7	56	875.4	404.1	363	138.0	89.1	517
Regional bus strike	43.8	7.5	164	1,011.8	510.6	465	229.2	847.1	1,256
Placebo strike	46.3	5.4	98	760.9	468.6	363	122.3	121.7	1,201
Non-strike	47.8	6.1	87,146	774.9	465.5	335,772	118.2	117.0	711,878
Rush hour	44.6	7.9	17,828	988.2	557.3	68,545	197.2	150.6	145,525
Non-rush hour	48.6	5.2	69,318	720.1	421.8	267,227	97.9	96.8	566,353
Total	47.8	6.1	88,106	775.9	457.0	338,782	118.9	123.1	719,661

Note: Hourly observations

Table 3a shows mean car speed for different strike categories. Note that when there are no strikes, speed during rush hours (44.6 km/h) is only 10% lower than during non-rush hours (48.6 km/h), in line with the idea that Rotterdam is an uncongested city. The table also shows the effect of strikes: car speed is distinguishably lower during full-day citywide strikes in comparison to non-strike hours. The difference in mean speed is about 3.3 km/h, so about 7%. At the same time, mean car and bicycle flows are substantially larger during full-day citywide strikes in comparison to non-strike days. During rush hours of full-day citywide strikes, mean

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[16] To be precise, intervals distinguish between 0-31, 31-41, 41-51, 51-57, 57-61, 61-71, 71-81, 81-91, 91-101, and above 101 km/h.
[17] For a number of cars, speed is unknown. We ignore these observations initially. In the sensitivity analyses, we re-estimate models with the proportion of cars with missing speed data as a control variable.

car speed is much lower, about 17%, compared to non-strike days.[18] For most strike categories, the number of speed observations is high enough to anticipate reasonably precise estimates. For example, for full-day citywide strikes, we have 294 observations about car speed, 854 about car flow and 2,212 observations for bicycle flow.

Full-Day Strike

Figure 3a – Car speed Thursdays June 2011   **Figure 3b – Car flow Thursdays June 2011**
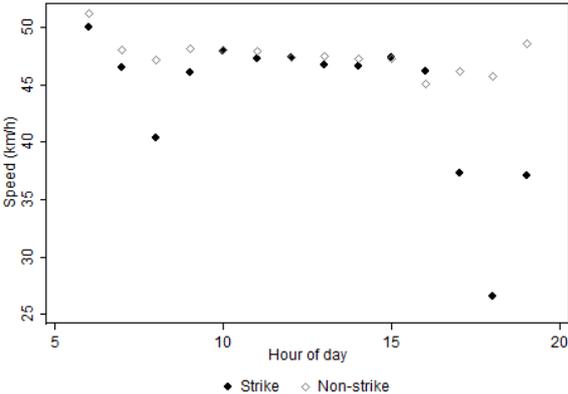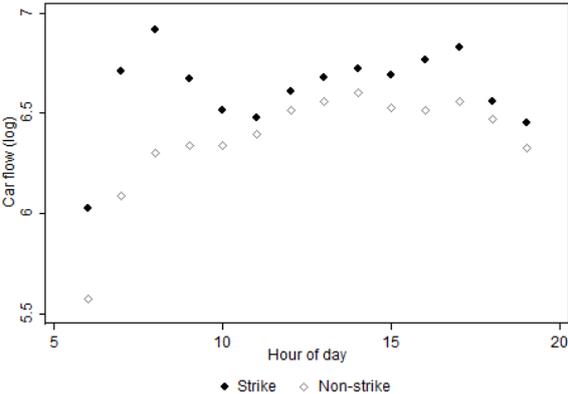
Partial-Day Strike

Figure 4a – Car speed Wednesdays May 2011   **Figure 4b – Car flow Wednesdays May 2011**
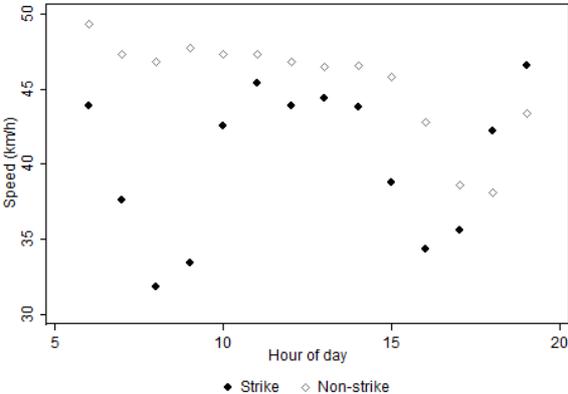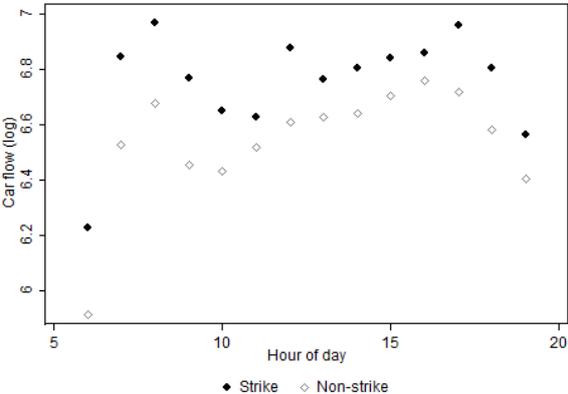
A visual examination of how transport outcomes vary over the day on days with and without strikes offers further insights which motivates our estimation methodology later on. Here, we compare transport outcomes on particular strike day to transport outcomes on non-strike days on the same weekday of the same month of the strike.

Figures 3a and 3b show car speed and car flow for a strike on a Thursday, on the 9th of June 2011 and for other (non-strike) Thursdays of the same month. During this particular

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[18] For rail and placebo strikes, speeds and flow are similar to non-strike days, suggesting the absence of an effect. For strikes with lower speed and a larger flow, standard deviations of speed tend to be larger (because of the increase in speed variation over the day).

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strike, which lasted a full day, car flows are larger and car speed is lower for most hours of the day compared to other (non-strike) Thursdays that month. This result for car flow also hold for bicycle flow, see Figure A2 in the Appendix.

Figures 4a and 4b provide information for a partial-day strike - between 5am and 9am - on Wednesday 11th of May 2011 and compare this to all other non-strike Wednesdays in that month. The outcomes of this partial strike appear similar to the full-day strike, suggesting that strikes effect speed also outside the strike period. Importantly, non-strike flow patterns between Thursdays and Wednesdays (see again Figures 3b and 4b) reveal weekday-specific flow patterns. For example, the morning rush hour is more pronounced on Wednesdays. It seems therefore important to control for the interaction of the week of the day and hour of the day fixed effects in the multivariate analysis.

3.4 Highway Traffic

We also make use of highway ring road data between 6am and 8pm for the year 2011 that are collected using induction loops (Snelder, 2010). Our data refer to the A16 motorway, east of Rotterdam. The maximum speed limit is 100 km/h on this stretch of the road. We use 5 minute data on both directions (that have 3 lanes each) for 7.6 kilometers (between the intersections with the northern and southern part of the ring road, A17 and A20). Because of frequent malfunction of loop detectors, data has been transformed to 100 meter virtual loop data (Vukovic et al., 2013).[19] We aggregate over time to create hourly observations of speed and flow.

We have 771,019 hourly observations, see Table 3b. Average highway flow is 2,963 cars per hour. Average speed is 96.8 km/h, close to the maximum speed limit, with a rather small standard deviation of 12.8 suggesting that congestion is not a major issue on this highway road. So, a priori, one does not expect particularly strong effects of a strike. This is confirmed by the data. During a full-day citywide strike, car speed is only 1.3 km/h lower, about 1.3%, than during non-strike hours. However, focusing on averages over the whole day is slightly misleading because during strike rush-hours, the effect of strikes is much more pronounced: for example, during citywide strikes, speeds are reduced by about 8% and highway flows increase by about 40%.

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[19] Induction loops are almost as frequent as virtual loop but have varying distances.

Table 3b – Summary statistics highway traffic

	Car speed			Car flow		
	Mean	SD	Obs.	Mean	SD	Obs.
Full-day citywide strike	95.5	10.4	6,426	3,033	1,244.0	6,426
Rush hour	86.6	15.5	1,224	4,340	886.4	1,224
Non-rush hour	97.6	7.4	5,202	2,753	1,113.1	5,202
Partial-day citywide strike	93.0	13.8	5,202	3545	957.0	5,202
Strike & rush hour	86.2	17.7	306	3,981	638.6	306
Strike & non-rush hour	91.4	14.8	459	3169	481.9	459
Non-strike & rush hour	83.9	19.3	1,377	4,160	1,123.5	1,377
Non-strike & non-rush hour	98.0	4.8	3,060	3,282	796.7	3,060
Placebo strike	100.6	11.9	1,836	2,288	1,089.2	1,836
Non-strike	96.8	11.9	757,555	2,960	1,150.4	757,555
Rush hour	92.6	16.3	208,903	3,354.3	1,484.9	208,903
Non-rush hour	98.3	9.3	548,652	2,809.4	951.7	548,652
Total	96.8	11.9	771,019	2,963	1,151.3	771,019

Again we show car flow for a full-strike and a partial-strike day and compare it to car flow on the same non-strike weekdays that month (Figures 5b and 6b). Similar to inner city roads, highway flows are larger during strike hours, especially for the full-day strike. In Figures 5a and 6a, it is shown that speed is lower during strike hours than during the same weekdays that month.

Full-Day Strike

Figure 5a – Car speed on Thursdays June 2011   **Figure 5b – Car flow on Thursdays June 2011**
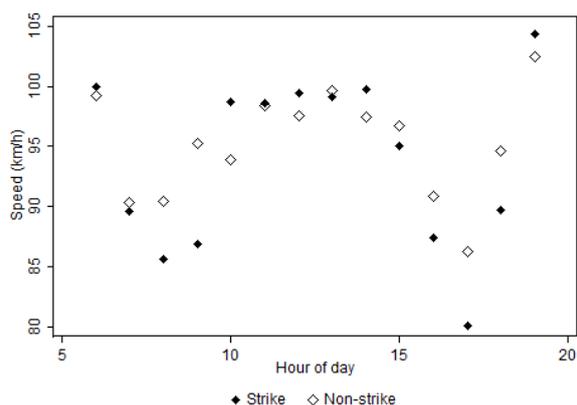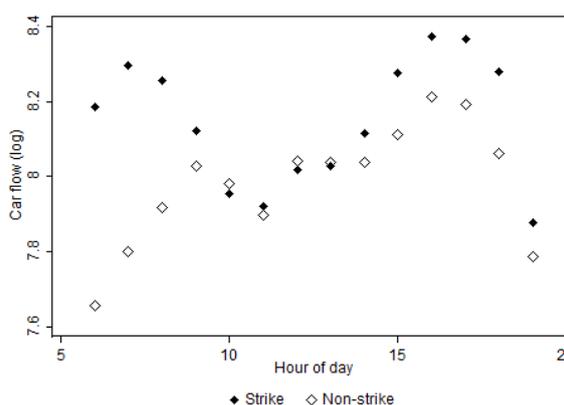
Partial-Day Strike

Figure 6a – Car speed on Wednesdays May 2011
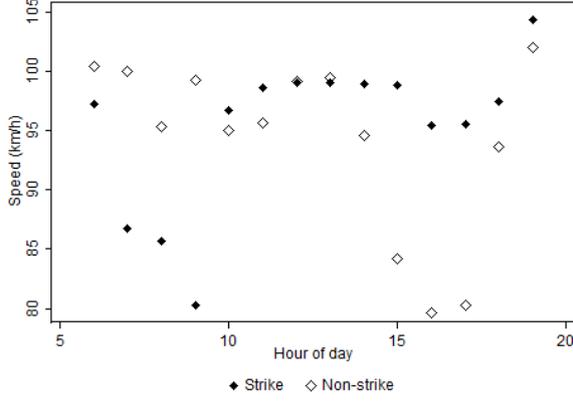
Figure 6b – Car flow on Wednesdays May 2011
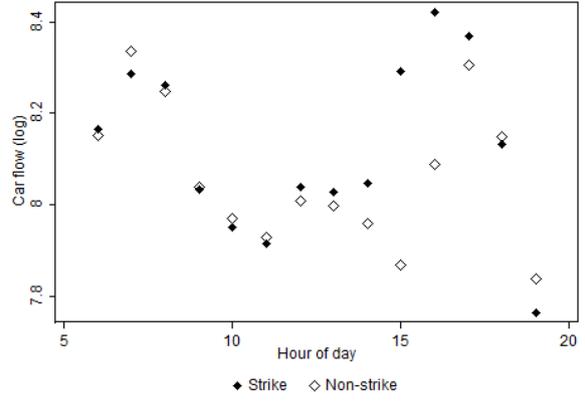
3. Method

To estimate the public transit strike effects, we use log-linear models.[20] We focus on the effect of citywide strikes. For these strikes, we distinguish between the effect of a full-day strike, the effect of a partial-day strike during strike hours and the effect of a partial-day strike outside strike hours. Because in the previous sections we have seen that the effects of strikes seem to differ for rush and non-rush hours, we also distinguish between rush hours and non-rush hours effects.

To estimate these different strike effects, we assume that the dependent variable $logY_{i,t,D}$ (i.e. car speed, car flow or bicycles flow), which is observed for a certain direction i, of hour t on day D, depends on a citywide full-day strike dummy F_D, a rush hour dummy R_t, a dummy variable $S_{t,D}$ for strikes at hour t of day D, control variables $X_{t,D}$, direction fixed effects a_i, and a random error term $u_{i,t,D}$ in the following way:

$$logY_{i,t,D} = \alpha_i + \beta_x X_{t,D} + [\beta_1 R_t + \beta_2(1 - R_t)]F_D$$
$$+ \left[\left(\beta_3 R_t + \beta_4(1 - R_t)\right)S_{t,D} + \left(\beta_5 R_t + \beta_6(1 - R_t)\right)\left(1 - S_{t,D}\right)\right]P_D + u_{i,t,D}. \quad (1)$$

In this way, the coefficient β_1 captures the citywide strike effect for a full-day strike during rush hours and β_2 captures the same effect but outside rush hours. For partial-day strikes during strike hours, β_3 captures the strike effect during rush hours and β_4 for non-rush hours. The effect during non-strike hours of partial-day strikes are captured by β_5 and β_6 for rush hours and non-rush hours, respectively.

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[20] Our results are robust to specification. For example, for a linear specification of speed we got almost identical results.

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The control variables $X_{t,D}$ include the placebo strikes, the regional bus strike, the rail strike and weather condition variables (precipitation, temperature and wind speed).[21] We also control for a range of time controls. We control for 'special' days (i.e. Christmas, Queens Day and the annual marathon), hour of the week (i.e., the interaction between hour of the day and day of the week) and week of the year (i.e., the interaction between week and year).[22]

The range of time controls are included because we have seen in the previous section that traffic flows follow certain time patterns during the day, but also to address the possibility that the strike date might be endogenous. For example, negotiating parties (i.e. unions, transport firms and the government) determine when strikes occur and might take the effect on car speed into account by not selecting certain days. So, occurrence of a strike is likely not fully random with respect to day of the week. This is also suggested by Table 1. For example, there are no citywide strikes on Fridays or Saturdays. Hence, including time controls is useful for consistency and efficiency reasons. Furthermore, to deal with heteroscedasticity and day-specific unobservables, we choose standard errors that are robust and clustered by day.

4. Empirical Results

4.1 Inner City Traffic

We report strike effects on car speed, car flow and bicycle flow of estimating equation (1) in Table 4. First, we discuss the citywide strike effects.[23] Our results in the first column indicate that a full-day citywide strike during rush hours decreases car speed by 15% (about 7 km/h), implying an additional 0.189 minutes per km traveled.[24] We interpret this as a strong effect: for example, the effect is about 50% higher than the one reported by Anderson (2014) for Los Angeles *highways* and several times higher than those assumed by Parry and Small (2009). Our result verifies the assumption by Anderson (2014) that car drivers on inner-city roads benefit substantially more from public transit through reduced car congestion than car drivers on highways.

This speed decrease is in line with a 9% increase in car flow during rush hours, as reported in the second column. This result is in line with the literature which shows that the

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[21] Daily travel demand, and bicycle travel in particular, depends strongly on weather, see, for example Thomas et al. (2013).

[22] Hour of the week contains a dummy for each combination of the hours of the day (14) and day of the week (7), in total 98. Week of the year has a dummy for each week (40) of the year (8), in total 320.

[23] See Table A2 in the Appendix for individual strike effects. Individual effects are more difficult to interpret given the presence of unobserved day-specific random error. By combining individual effects into categories, any small sample bias due to day-specific random error is substantially reduced.

[24] We calculate the additional time per kilometer by multiplying the percentage of speed reduction with the time it takes to travel 1 km. Note that 0.151*3600/(47.8*60) = 0.189, where 47.8 is the average speed. Also, note that we interpret coefficients as percentage changes.

strike effect on car flow is usually in the range of 5% to 30% (Van Exel and Rietveld, 2001). Furthermore, a full-day citywide strike increases bicycle flow by 24% implying that a large share of travelers switch to bicycle use (rather than car use), which presumably reduces the car flow increase and therefore the speed reduction of a strike. Bicycle ownership and use is much higher in the Netherlands than in other countries in the world, so this result is likely specific to the Netherlands. The reduction in speed during non-rush hours is smaller and only 6%. Hence, one immediate, but maybe obvious, implication is that the benefit of public transit provision in terms of congestion reduction is smaller outside rush hours.[25]

Table 4 – Car speed, car and bicycle flow (by strike)

	Car speed (log)		Car flow (log)		Bicycle flow (log)	
Full-day citywide strike						
Rush hour	-0.151	***	0.094	***	0.244	***
	(0.053)		(0.021)		(0.057)	
Non-rush hour	-0.064	**	0.069	***	0.145	**
	(0.029)		(0.024)		(0.062)	
Partial-day citywide strike						
Rush and strike hour	-0.209	***	0.142	***	0.257	***
	(0.051)		(0.020)		(0.047)	
Non-rush and strike hour	-0.006		0.027		0.100	**
	(0.010)		(0.020)		(0.047)	
Rush and non-strike hour	-0.071	***	0.014		-0.009	
	(0.022)		(0.024)		(0.050)	
Non-rush and non-strike hour	-0.020		0.010		0.065	
	(0.012)		(0.012)		(0.040)	
Placebo strike	0.001		-0.000		-0.023	
	(0.013)		(0.013)		(0.050)	
Regional bus strike	-0.032	**	0.033		0.186	***
	(0.014)		(0.024)		(0.037)	
Rail strike	0.004		0.068	***	0.117	
	(0.017)		(0.017)		(0.092)	
Location fixed effects	Included		Included		Included	
Hour of week fixed effects	Included		Included		Included	
Month fixed effects	Included		Included		Included	
Week of year fixed effects	Included		Included		Included	
Year fixed effects	Included		Included		Included	
Weather controls	Included		Included		Included	
Number of observations	88,106		338,782		719,661	
R²	0.4002		0.7789		0.7474	

Note: ***, **, * indicate 1%, 5% and 10% significance levels. Standard errors in parentheses are robust and clustered by day. The rail and placebo strike effects on car speed are based on one and two strikes, respectively.

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[25] For non-rush hours, travel demand tends to be lower. Moreover, there is a lower share of commuters, so trip rescheduling and trip cancellation is likely less costly to travellers. However, increases in car flows are similar (the p-value 0.174 of a F-test is) for full-day strike rush and non-rush hours. The same holds for bicycle flows (p-value 0.113).

Later on, for our welfare calculations, it is accurate to use a weighted average of the full-day citywide strike effect, because we are interested in the average effect of a strike for each car traveler, so we wish to take into account that rush hours are less frequent than non-rush hours, but we also like to take into account that during rush hours, there is a higher flow of cars. We weight the rush and non-rush hour coefficients with their share of hours over the day and their share of vehicle flow (see Table 3a).[26] On average, full-day citywide strikes decrease speed by 10.3% and increase flow by 8.1%, implying 0.129 minutes additional travel time per kilometer traveled.

For partial-day strikes, outside strike hours, but during rush hours, strikes decrease speed by a similar percentage (7%).[27] In addition, our results suggest that the speed effects of strikes that last a few hours are similar to full-day strikes strongly suggesting that a continuous supply of public transit during the full day is essential for travelers. We have also estimated models where we allow for strike effects on days before and after the strike. We find no changes in car flow or speed that extend to days before and after the strike. Interestingly, we find a (very) small effect on bicycle flow for the working day after a strike but no effect two working days after the strike. Apparently travelers hardly change their travel behavior 'permanently' due to a strike.[28]

We find no effect on speed by the three placebo strikes. This gives us more confidence in the methodology used. As argued above, placebo strikes are defined by us as (announced) strikes which are canceled, so given a large effect of announcement, canceled strikes may not be interpreted as placebo strikes.[29] For this reason, we have tested the effect of announcement by including an announcement dummy. We do not find an effect of announcement on speed, suggesting that canceled strikes can be interpreted as placebo strikes.

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[26] The share of rush hours of the number of hours included in our analysis is 0.29. The share of car flow during rush hours is 0.57 (see Table 3a). Note that 0.103*3600/(47.8*60) = 0.129.

[27] For partial-day strikes, the point estimate of a strike during rush hours and strike hours is 21%, but despite the larger coefficient, the effect is not statistically different (p-value 0.426); likely due to the limited number of observations which is only 12.

[28] The regional bus strike particularly increases bicycle flow (by 19%). This is a relatively large increase, considering that the strike took place in non-rush hours and a low modal share of regional buses. An explanation for this relatively large effect is that the strike overlapped with national school exams, so many students switch to bicycle use. We find no effect on inner city car speed for national rail strikes. We also find no effect on bicycle flow. The latter is not so surprising because bicycle and rail are complements in the Netherlands as about half of travelers use the bicycle as an access or egress mode for rail. One explanation for these findings is that the share of rail in passenger transport is low in Rotterdam (2.7%), see De Vries (2013). Moreover, there are only two rail strikes, so these estimates are less reliable.

[29] Strike announcement has likely an effect on travel behavior according to Van Exel and Rietveld (2001).

4.2 Sensitivity analyses for car speed on inner city roads

To verify the robustness of our results for car speed we conduct a range of sensitivity analyses. We find our results to be robust to various speed specifications. Table 5 shows the main results. For example, it is well known that the pneumatic tube speed measurement techniques perform less well at lower speeds. Consistent with that, we observed that there is a higher proportion of missing observations at lower speeds. Hence, in the first column, we include the proportion of cars with unknown speed as a control variable. We find that strike effects are somewhat reduced, but not extremely.[30] Note that this control variable is highly endogenous and likely biases the strike effect towards zero, so we interpret the latter specification as an extreme underestimate and prefer the estimates of Table 4 without this additional control variable.

In the calculation of speed, we have assumed that cars in the lowest speed interval – less than 31 km/h – travel at an average speed of 15 km/h. To see how much our results depend on this assumption, we estimate a model where all cars in the lowest speed interval are assumed to travel at 31km/h. Now we find that during full-day citywide strike rush hours, speed declines by 7% (see column 2). Note that we interpret this estimate as the minimum effect because this approach strongly biases our results towards zero. To prove this latter point, we estimate a model where the dependent variable is the share of speed observations above 31 km/h (see column 3). Reassuringly, the signs of the strike effects are in line with the main results: for example, given a full day citywide strike, the share of speed observations that exceed 31 km/h drops by 0.118 during rush hours.

Four of the 13 citywide strikes are not complete, in the sense that some public transit is still supplied for the metro or that only the time schedule has been reduced (see Table 1). Consequently, it is plausible that our estimates are underestimates of complete strikes which are more representative to capture the congestion relief benefit of public transit. We therefore re-estimate the model excluding these four incomplete strikes. The rush hour, full-day citywide strike effect becomes more pronounced and is now equal to -0.201. This result is in line with the idea that complete strikes entail larger speed reductions. Hence, importantly, it is plausible that using the estimates of Table 4 will lead to underestimates of the congestion relief benefit.

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[30] In addition, as expected, we find a negative relationship between the number of cars with unknown speed and average speed.

Table 5 – Car speed, car and bicycle flow (by strike)

	Car speed (log)		Car speed (log)		Speed share		Car speed (log)		Car speed (log)	
Full-day citywide strike										
Rush hour	-0.115	***	-0.073	***	-0.118	***	-0.201	***	-0.230	***
	(0.039)		(0.023)		(0.044)		(0.045)		(0.060)	
Non-rush hour	-0.045	**	-0.032	**	-0.049	**	-0.081	**	-0.053	
	(0.019)		(0.014)		(0.024)		(0.034)		(0.039)	
Partial-day citywide strike										
Rush and strike hour	-0.190	***	-0.103	***	-0.172	***	-0.103	***	-0.286	***
	(0.047)		(0.017)		(0.049)		(0.015)		(0.074)	
Non-rush and strike hour	-0.001		-0.006		-0.001		-0.009		-0.003	
	(0.009)		(0.005)		(0.007)		(0.008)		(0.020)	
Rush and non-strike hour	-0.057	***	-0.034	***	-0.050	**	-0.058	**	-0.156	***
	(0.014)		(0.008)		(0.020)		(0.025)		(0.040)	
Non-rush and non-strike hour	-0.020	*	-0.013	*	-0.014		-0.027		-0.031	
	(0.011)		(0.007)		(0.010)		(0.018)		(0.028)	
Placebo strike	0.001		-0.004		0.005		0.001		0.030	
	(0.008)		(0.005)		(0.014)		(0.013)		(0.037)	
Regional bus strike	-0.024	***	-0.010	*	-0.038	***	-0.032	**	-0.097	***
	(0.008)		(0.006)		(0.013)		(0.014)		(0.010)	
Rail strike	-0.007		-0.006		0.012		0.017		0.023	
	(0.012)		(0.010)		(0.014)		(0.016)		(0.046)	
Proportion unknown speed	-2.412	***								
	(0.139)									
Time/weather controls	Included		Included		Included		Included		Not included	
Number of observations	88,106		88,106		88,106		87,882		88,106	
R²	0.5898		0.6500		0.1871		0.4007		0.0041	

Note: In the second column, cars below 31km/h censored at 31. Third column, the dependent variable is the share of cars at speeds exceeding 31km/h. Fourth column, we exclude the four citywide strikes that were not a complete public transit cancellation. Last column, we do not include controls. See Table 4 for control variables. ***, **, * indicate 1%, 5% and 10% significance levels. Standard errors in parentheses are robust and clustered by day.

In the fifth column of Table 5, we re-estimate the model without any time or weather condition control variable. Not surprisingly, standard errors tend to increase due to a less efficient estimation specification. The effects are identical *in sign* to those in Table 4 and usually of a similar magnitude, which gives confidence in our results in the sense that overall results do not strongly depend on these control variables.

4.3 Highway Traffic

We now focus on the strike effects on the highway ring road. It appears that citywide strikes also have a negative effect on highway speed, see Table 6. However, in comparison to inner city roads, speed reductions are much smaller. In particular, even during rush hours, the effect

is only about 3.7% (4 km/h) during full-day citywide strikes. This decrease corresponds to an increase of 0.023 minutes travel time per km traveled.[31]

Table 6– Car speed and flow on highways

	Car speed (log)		Car flow (log)	
Full-day citywide strike				
Rush hour	-0.037	***	0.031	*
	(0.010)		(0.017)	
Non-rush hour	-0.025	***	-0.017	
	(0.010)		(0.028)	
Partial-day citywide strike				
Rush and strike hour	-0.068	***	-0.040	*
	(0.018)		(0.023)	
Non-rush and strike hour	-0.071	***	-0.044	**
	(0.013)		(0.021)	
Rush and non-strike hour	-0.035		-0.073	***
	(0.058)		(0.024)	
Non-rush and non-strike hour	0.021	*	-0.016	
	(0.011)		(0.025)	
Placebo strike	-0.015		0.002	
	(0.010)		(0.021)	
Number of observations	771,019		771,019	
R²	0.2152		0.8175	

Note: See Table 4 for control variables. ***, **, * indicate 1%, 5% and 10% significance levels. Standard errors in parentheses are robust and clustered by day.

The (weighted) average speed decline of a full-day citywide strike is even slightly lower and equal to 3%, 0.019 minutes travel per km traveled.[32] We will use this result in our welfare calculations later. We interpret this result as a small effect: it is several times smaller than reported by Anderson (2014) for Los Angeles (and about half of the assumption made by Parry and Small, 2009). We can only speculate about explanations for this difference in the magnitude of the effect. The main explanation is likely that the highways in Los Angeles that are chosen by Anderson (2014) are more congested than those of Rotterdam.

Despite the presence of a strike effect on speed, we find little or no increase in flow on highways. Importantly, this finding is similar to Lo and Hall (2006) and Anderson (2014). One explanation is purely statistical, in the sense that the standard errors are too large to estimate the effect at conventional significance levels. An alternative explanation, which is equally plausible, is that congestion on highways induces queuing at bottlenecks which

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[31] Note that 0.037*3600/(96.8*60) = 0.023. Reassuringly, we find no impact of a placebo strike effect.
[32] For rush hours, the share of hours over the day is 0.28 and the share of flow is 0.61. Note that 0.030* 3600/(96.8*60) = 0.019.

prevent cars from entering the highway, so flows into the highway decline. The latter happens much less within inner cities and then only in case of extreme congestion (as observed for Asian cities by Geroliminis and Dagazo, 2008). [33] In Rotterdam, this does not occur: within the inner city, there are very few observations with low car speed and flow (which are likely due to roadworks, accidents etc).

4.4 Traffic accidents

So far, we have focused on car speed as affected by public transit strikes. However, it is possible that public transit provision effects traffic accidents, because public transit influence the travel mode of travelers as well as the speed on the road which both influence the frequency of accidents (Aljanahi et al., 1999). A priori, the effect of public transit strikes is ambiguous. The numbers of accidents is thought to increase with an increase in bicycle and traffic, whereas the number of severe incidents falls with car speed. So, it seems possible that during strikes the number of accidents increases whereas accident severity decreases.

We have (police-reported) daily traffic accidents data for Rotterdam for the years 2000 to 2009 (except for 2008). As is common in the literature using accident data, minor accidents are often not reported to the police, and so the data set comprises a larger share of severe accidents. The descriptives suggest that there might be a negative effect of strikes on the number of accidents: the average number of traffic accidents on strike days is substantially less than on other days (7.0 compared to 9.2). This result is consistent with the idea that public transit supply reduces accidents. However, when we estimate the effect of strike on number of accidents with similar controls as above, the results do not show any strike effect on accidents.

5. Public transit congestion relief benefit

We determine the welfare loss due to additional time losses by car travelers given a full-day citywide strike on a weekday. Arguably, this loss is equivalent to the public transit congestion relief benefit. We will assume a hourly value of time of €14 per person implying a hourly value of time of €20 per car.[34]

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[33] For support of this claim, see Figures A4 and A5 in the Appendix where both for the highway as well as the inner city, the relationship between flow and speed is shown, commonly known as the fundamental diagram of traffic flow, see Small and Verhoef, 2007, p.84-88.

[34] In Rotterdam, a car contains on average 1.5 persons (CBS, 2014). We assume that the same occupancy rate applies during strikes. The assumed value of time is slightly higher than the commonly used value of time for commuters based on stated preference studies for the Netherlands, which is 10 euro. Our assumption can be justified because stated preference studies likely underestimate the true value and because a substantial proportion of car drivers travels for business for which the value of time likely exceeds €30 per hour. Assuming

Table 8 – Number of trips per day for Rotterdam metropolitan area

	Non-strike day	Strike day (% change)	Differences
Public transit	348,000	-100%	-348,000
Car (driver)	804,000	+7.5%	60,300
Car (passenger)	408.000	+7.5%	32,600
Bicycle	588,000	+17%	99,960
Trips not replaced by car or bicycle			155,140

Note: Inner city train travel that that does not include another local form of local transport is negligible.

In Rotterdam, 1.2 million inhabitants conduct each day 348,000 public transit trips, 804,000 car driver trips, 408,000 car passenger trips, 588,000 bicycle trips and 765,000 walking trips, so in total 2.913 million trips (De Vries, 2013), see Table 8. During a full-day citywide strike, public transit is not available, so there are no public transit trips. Our estimates indicate that a strike induces car flow to increase by 7.5%, so 60,300 additional car driver trips and 32,600 additional car passenger trips, and bicycle flow to increase by 17%, so 99,960 trips. This implies that the increase in bicycle use is about equal to the increase in persons which travel by car. Furthermore, it means that 192,860 out of 348,000 canceled public transit trips are substituted by a car or bicycle trip. The other 155,140 trips are either rescheduled to another day, made by another mode not observed by us, most likely walking, or fully canceled.[35]

In Table 9, the annual congestion relief benefit is calculated for a range of assumptions. In Rotterdam, cars trips have an average length of 15 km of which 62% are driven on inner city roads and the remaining 38% on highways, see column 1 of Table 9.[36] Given the estimated speed decrease of 10% on inner city roads (weighted averaged over hours and flows) and 3% on highways, a strike induces an additional external cost of congestion of €376,835. The majority of this cost, €345,633, is on inner city roads, and additional €31,201 on highways.[37] The annual public transit congestion relief benefit is then about €95 million

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different value of time values for rush hours and nonrush hours might be more reasonable, but it appears that our results are not so sensitive to that. For example, we assume that the value of time is €25 per car during rush hours and €15 per car during non-rush hours then we obtain almost identical benefits.

[35] These results are in line with previous studies which report that during strikes 20% of canceled public transit trips are substituted by walking, 10% fully canceled and 10% rescheduled (PbIVV, 1984; van Exel and Rietveld, 2001). One of the main arguments against public transit subsidies is a low price cross elasticity between public transit and car use. Note that we do not examine changes in prices. However, we find that a quarter of the public transit users substitutes to car use during strikes.

[36] The share of car travel distances on inner city roads and highways are about the same in the Netherlands (CBS, 2014). For cities such as Rotterdam, one expects a higher share of inner city road use. On the highway ring road around Rotterdam we observe 331,744 trips per day, suggesting that 62% of trips are on inner city roads.

[37] The inner city road congestion relief benefit given a trip length of 15km, 864,300 car trips and a €20 per hour value of time is equal to 0.129*15*864,300*0.62*20/60 = €452,807. The highway congestion relief benefit is then equal to 0.022*15*864,300*0.38*20/60 = €31,201.

(assuming 252 working days), so about €79 per inhabitant. This excludes any benefits of public transit provision on weekends that we assume to be negligible, so this is likely an underestimate. Given 721 million public transit passenger kilometers (OVPRO, 2014), the congestion reduction benefit per public transit kilometer is €0.13. This benefit is substantial given that the cost per public transit kilometer is €0.46. In addition to congestion welfare losses there are rescheduling costs to car travelers.[38] We do not include these costs, nor do we include the loss to public transit ticket holders or any other external cost of car driving that are likely an order of magnitude smaller than the effect through congestion.[39]

Table 9 – Congestion relief benefit

	(1)	(2)	(3)
Area affected	Metropolitan	City	Metropolitan
Number of inhabitants affected	1.2 million	0.6 million	1.2 million
Car trips weekday	804,000	402,000	804,000
Average trip distance	15 km	10 km	15 km
Value of time per car	€20 per hour	€20 per hour	€20 per hour
Speed benefit inner city	0.129 minutes per km	0.129 minutes per km	0.169 minutes per km
Speed benefit highway	0.019 minutes per km	0.019 minutes per km	0.019 minutes per km
Inner city to highway km ratio	62/38	50/50	62/38
Daily public transit benefit inner city	€345,633	€139,368	€452,807
Daily public transit benefit highway	€31,201	€23,768	€31,201
Overall public transit benefit	€376,835	€163,136	€484,008
Annual public transit benefit (weekdays)	€95 million	€41 million	€122 million
Public transit subsidies	€200 million	€200 million	€200 million
Congestion relief benefit to subsidies	47%	21%	61%

The costs of providing public transit in Rotterdam are partially covered by subsidies, about €0.28 per public transit kilometer.[40] So, the congestion relief benefit is about 47% of subsidies.[41] It is useful to examine this result under different assumptions. For example, if we

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[38] We find that the peak hours start earlier and end later for citywide strikes, suggesting that these costs are not zero.

[39] Assuming, that the external cost of CO_2 is €100 per km, the external benefit is only €0.002 per public transit km.

[40] Annual subsidies for public transit were €200 million (Stadsregio Rotterdam, 2012). That is about €166 per capita, and about 0.3% of average gross salary. By comparison, bicycle infrastructure expenditure by the municipality is only €30 million per year (Savelberg, 2013). Note that bicycle lanes tend to reduce the width of roads, so the social cost of bicycle infrastructure will be higher than the expenditure by the municipality.

[41] Total operational cost of public transit was about €333 million. The farebox recovery for Rotterdam was between 35%-40% of operational cost, similar to many other cities with extensive public transit in Europe and the United States.

assume that the specification of complete strikes is more indicative of the congestion relief benefit (Table 5, column 4), then this benefit is at least 61% of subsidies (see column 3). In contrast, if we take the most conservative assumptions by assuming a trip length of 10 km, an equal split in distance traveled on highway and inner city roads, and that only inhabitants in the city of Rotterdam (and not the whole metropolitan area) are affected by the strike, then the congestion relief benefit is only 21% of the subsidy (column 2). Hence, the congestion relief benefit is likely between 21% to 61% of the subsidy level.

This suggests that the congestion relief benefit alone is substantial but insufficient to justify the current supply of public transit in Rotterdam. Additional gains of public transit provision, such as economies of scale in public transit provision, since marginal cost of public transit is less than average cost, and productivity increases (Graham, 2007) might support current levels of subsidies.[42] To do an overall welfare analysis of public transit provision for Rotterdam is beyond the scope of this paper.

It is important to emphasize that there are some reasons to believe that we have overestimated the congestion relief benefit but there are also reasons to believe that we have underestimated the congestion relief benefit of public transit. First, we have estimated the average, rather than the marginal, congestion relief benefit of public transit (by examining the effect of a public transit reduction towards zero). The marginal public transit benefit is likely decreasing in the public transit provision level (as congestion is likely a convex function of number of cars, see Small and Verhoef, 2007) and therefore smaller than the average benefit estimated by us. For policy recommendations, we are mostly interested in marginal changes in public transit supply, so, from this point of view, our estimates can be interpreted as underestimates. However, because congestion levels are rather low within Rotterdam, and because congestion within cities is almost linearly related to car flow for cities with low congestion (Geroliminis and Dagazo, 2008), it is plausible that this issue is not quantitatively important.

Second, strikes can be interpreted as crude approximation of counter-factual long-term adjustments in public transit supply as impact-related decisions regarding car ownership, work and residence location are ignored.[43] It is extremely plausible that we underestimate the long-term congestion relief benefit by analysing the effect of strikes of short duration. First,

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[42] Further, there are egalitarian reasons for subsidies, since public transit disproportionately supports the economically less well-off parts of society (see, e.g., Johnson, 2014, Compton and Pollack, 2014).

[43] As it is well known, household and firm location decisions depend on travel times, see, for recent contributions, Kok et al., 2014 and Johnson, 2014. Most papers reviewed by Van Exel and Rietveld (2001) do not suggest permanent losses in transport passengers for the mode under strike, because strikes are temporary. The estimated loss of public transit passengers after a strike is usually between 0.3% and 2.6%.

for these trips, it is likely that about 20% are canceled or rescheduled (see also PbIVV, 1984; van Exel and Rietveld, 2001). For longer periods without public transit, particularly for commuting, it is unlikely that these trips are canceled or rescheduled. Second, in cities with good public transit, it is plausible to assume that car ownership is substantially lower than in other cities. For longer periods without public transit, current public transit travelers are likely to increase car ownership and use, so increasing car congestion. In Dutch rural areas, where public transit is virtually absent, car ownership per household is 30% higher than in urban areas (CBS, 2014). Note that car ownership in rural areas is also lower because of lower densities so a 30% increase is likely a substantial overestimate of the increase in car ownership due to the absence of public transit.

One may also overestimate the public transit congestion relief benefit by focusing on short duration strikes, because residential and workplace location decisions are both affected by travel times to work and access to certain modes of transportation (Kantor et al., 2014). Without public transit, some households and firms would re-evaluate their location decision and may move closer to each other. However, this effect of location adjustments is likely smaller than the increase in congestion due to increase in car ownership.[44]

6. Conclusion

Public transit provision is a widely-accepted policy measure to reduce road congestion. The level of public transit provision and therefore the level of subsidies to public transit are usually subject of debate in many countries (e.g., Parry and Small, 2009; Anderson, 2014). We add to this debate by estimating the effect of multiple public transit strikes on car travel time losses for inner city roads and highways of Rotterdam, which is a rather uncongested city. This quasi-natural experiment allows us to determine the congestion relief benefit, i.e. the monetary value of a reduction in car congestion due to public transit provision.

We demonstrate that during a citywide strike, car speed within the city decreases by about 10%. For highways, strikes exhibit a much smaller speed reduction of about 3%. During rush hours, the reduction in speed is more pronounced. These results imply that during rush hours, public transit provision reduces car travel time on inner city roads by about 0.2 minutes

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[44] One of the drivers of strikes is the joint cost to firms and employees that bargain about labour conditions such as wages, see Franzosi (1989) and Card (1990). Information about these cost is crucial to the negotiating parties' concession curves and hence bargaining. In case of public transit, outsiders of this bargaining process include car drivers when governments have no influence on the outcome of the bargaining process. When the transit firm is controlled by the government that is aiming to maximise welfare then it may be efficient that the government induces public transit firms to accept terms which would have been rejected from a private firm's consideration alone, although this may result in higher wages (Proost, 2014).

per kilometer travelled, whereas it reduces car travel time on highways by 0.02 minutes per kilometer. Hence, for cities such as Rotterdam, travelers on inner city roads benefit much more from public transit provision than highway travelers. Our main finding is that for Rotterdam, the congestion relief benefit is substantial and equal to about one third of the public transit operating cost and half of subsidies to public transit. Consequently, this indicates that even for cities that are mildly congested, substantial subsidies to public transit are economically justified.

We also show that on a strike day, the increase in number of persons who travel by bicycle is about equal to the increase in the number of persons who travel by car. Although this may seem a typical result for a city in a country that is well known to have above-average bicycle use, we emphasise that bicycle use in Rotterdam is low from a Dutch perspective. This finding supports the claim that bicycle-promoting policies (such as bicycle lanes) may be a cost-effective way of reducing car travel time losses.

Appendix

Figure A1 – Measurement stations bicycle

Source: Rotterdam municipality.

Table A1 – Number of measurement locations and directions

Transport mode	Locations	Directions
Car flow	8	12
Car flow and speed	2	4
Bicycle flow	20	36

Figure A2 – Bicycle flow Thursdays June 2011
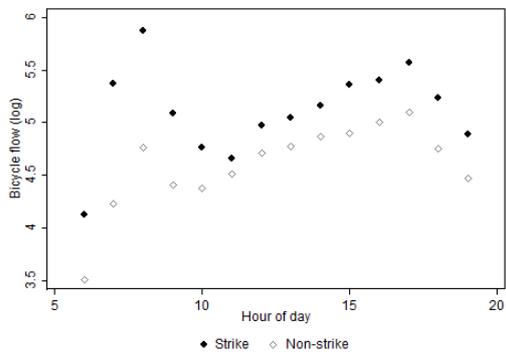
**Figure A3 – Bicycle flow Wednesdays May 2011**
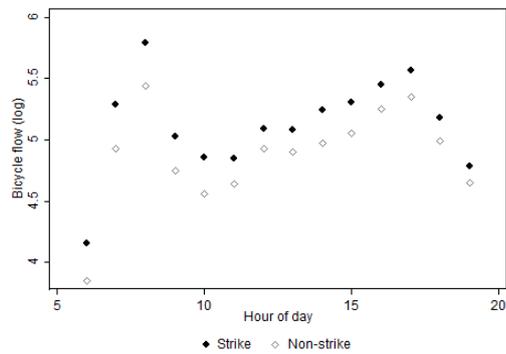
Figure A4 – Speed-flow relationship inner city roads
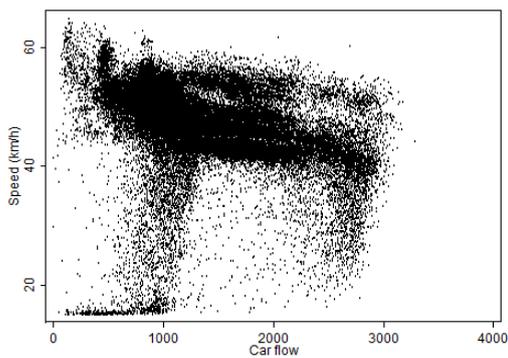
Figure A5 – Speed-flow relationship highway
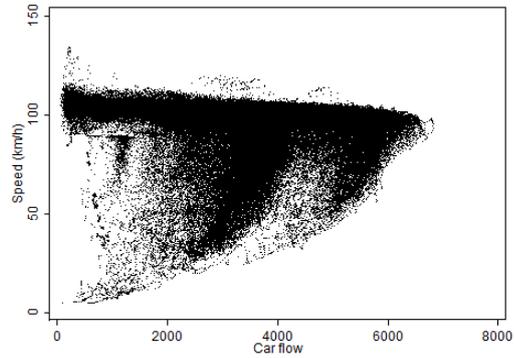
Table A2 – Bicycle flow demand, car demand and car speed on inner city roads

Strike mode	Car speed (log)		Car flow (log)		Bicycle flow (log)	
Rail strike 21-12-2000			0.108	***	0.069	**
			(0.028)		(0.035)	
Citywide strike 14-10-2004	-0.093	***	0.126	***	0.510	***
	(0.005)		(0.013)		(0.055)	
Rail strike 17-06-2005	0.011	**	0.059	***	-0.055	**
	(0.005)		(0.016)		(0.022)	
Citywide strike 29-06-2005	-0.196	***	0.114	***	0.037	
	(0.018)		(0.024)		(0.051)	
Citywide strike 18-09-2006	-0.042	***	0.091	***	0.072	**
	(0.014)		(0.018)		(0.029)	
Citywide strike 25-09-2006	-0.165	***	0.162	***	0.167	***
	(0.006)		(0.011)		(0.032)	
Citywide strike 16-02-2011	-0.001		0.039	***	0.191	***
	(0.009)		(0.010)		(0.062)	
Citywide strike 11-05-2011	-0.187	***	0.144	***	0.250	***
	(0.027)		(0.014)		(0.046)	
Citywide strike 09-06-2011	-0.097	***	0.012		0.306	***
	(0.013)		(0.044)		(0.030)	
Citywide strike 08-10-2003	0.004		0.031	***	0.245	***
	(0.007)		(0.010)		(0.041)	
Citywide strike 04-09-2006	-0.002		-0.028	**	-0.019	
	(0.005)		(0.012)		(0.066)	
Citywide strike 15-11-2006	0.011		-0.028	*	0.065	
	(0.016)		(0.017)		(0.065)	
Citywide strike 12-04-2011	0.008		0.060	***	0.022	
	(0.058		(0.014)		(0.032)	
Citywide strike 29-06-2011	-0.022		0.040		0.152	
	(0.014)		(0.048)		(0.084)	
Citywide strike 20-11-2011	0.005		0.019	**	-0.077	***
	(0.002)		(0.008)		(0.020)	
Regional bus strike 20-05-2008	0.010		-0.014		0.050	
	(0.012)		(0.021)		(0.057)	
Regional bus strike l 21-05-2008	-0.114	***	-0.037	**	0.085	
	(0.013)		(0.020)		(0.056)	
Regional bus strike 22-05-2008	-0.058	***	0.014		0.027	
	(0.013)		(0.021)		(0.056)	
Placebo Rail 02-04-2001			0.024		0.173	***
			(0.016)		(0.020)	
Placebo Citywide strike 06-10-2009	-0.022	***	-0.0227	*	-0.046	*
	(0.007)		(0.0133)		(0.025)	
Placebo Citywide strike 06-11-2011	0.019	***	-0.007	***	-0.114	***
	(0.007)		(0.008)		(0.023)	
Controls	Included		Included		Included	
Number of observations	88,106		338,782		719,661	
R²	0.4006		0.7790		0.7474	

Note: Strike dummies apply for hours when strike is reported. For the 2000 rail and 2001 placebo strike there is no speed information available. See Table 4 for control variables. ***, ** indicate 1 and 5% significance levels. Standard errors are robust and clustered by day.

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