CHAPTER 4

AN ECONOMIC ANALYSIS AND AN ECONOMETRIC INVESTIGATION OF HYPERCONGESTION

4.1 Introduction

Road traffic hypercongestion is usually taken as meaning circumstances in which increased flow on a network (rather than onto the network) results in greater speed rather than less as is the case in ordinary congestion. It is often associated with very low traffic speeds and is regarded as causing a severe economic externality in most urban areas. In spite of the serious nature of this problem, transport economics has encountered some problems in explaining and estimating the marginal external hypercongestion cost. The conventional estimation of the marginal external congestion cost makes use of the engineering concept of speed-flow relationships. However, as reviewed in Chapter 2, the conventional analysis focuses on a model for the marginal external congestion cost in ordinary congestion and this is insufficient to explain the marginal external hypercongestion cost. Implausibly, the conventional analysis might be interpreted as suggesting the unlikely outcome of hypercongestion being a positive externality, see Walters (1961), Johnson (1964) and Newbery (1987 and 1989). Thus, a different economic theory of hypercongestion is required.

In this and Chapter 3, we develop a density based theory of hypercongestion that is capable of being estimated using speed-flow data. In this Chapter, we show that for London urban roads, the hypercongested speed-flow relationship is not as usually depicted in textbooks but is essentially, and not surprisingly, a vertical relationship that may represent bottleneck congestion. However, using the Chalerm Mahanakorn Expressway in Bangkok, we show that the speed-flow relationship for this Expressway has the standard form and the related marginal external hypercongestion cost is very high.

In the previous Chapter, a theory of ordinary congestion is developed on a uniform road section for the case of uniform road users with perfect knowledge of traffic conditions. In this and Chapter 3, it is shown how this theory can be simply extended to the case of hypercongestion. This analysis is based on the proposition that it is an excessive density of road users that causes hypercongestion and it is shown how the theory relates to the standard speed-flow analysis. In this Chapter, it is shown how real world data taken from the measurement of speeds and flows in the area of Central London and the Chalerm Mahanakorn Expressway in Bangkok can be used to estimate the marginal external costs of hypercongestion.

4.2 Theoretical Model of Hypercongestion

The speed-flow economic analysis of the marginal external costs of congestion is, as is shown in the review Chapter, the dominant model of the economics of road congestion. However, it is argued, in the review Chapter and Chapter 3, that the analysis can be reworked and is helpful in explaining the cost of congestion when density and speeds are not constant. The previous Chapter’s discussion analysis is not repeated in its entirety but the analysis and discussion relevant to examining hypercongestion is extended.

This Chapter analyses the marginal external hypercongestion cost using speed-density relationships in manner similar to Chapter 3. For a hypercongested state, an increasing traffic flow *F* increases speed *V* as depicted in Figure 3.2.1 and discussed in the hypercongestion literature in Chapter 2.

What is important in examining hypercongestion is that, when considering the additional vehicle causing the hypercongestion externality, the additional distance travelled by this vehicle is less than the displaced distance travelled by all other vehicles, ie

$$\left|dD\ V\right| < \left|dV\ D\right| \qquad (4.2.1)$$

The implication of this condition is that the capacity of the road has been exceeded. The greater density following from the additional vehicle results in a fall in the total net vehicle kilometres travelled during the period of the additional vehicle being on the road. Thus, the existing vehicles on the road have to travel at some later time further than the additional vehicle travelled. If these latter distances are travelled in an adjacent period of hypercongestion, there is an explosive increase in density.

The inherent instability of the equilibrium of hypercongestion can be investigated but oversimplified by assuming that the level of density is constant across all time periods. In Chapter 3, it is shown that the total additional journey time caused to all other users by travel of $dD\ V\ dt$ by the additional vehicle is

$$dD\,dt\ \left|\varepsilon_{VD}\right|\ \left(1+\left|\varepsilon_{VD}\right|+\left|\varepsilon_{VD}\right|^{2}+\ldots\ldots\right) \qquad (4.2.2)$$

The expression has no upper limit for an elasticity ($|\varepsilon_{VD}|$) of one or greater than one in magnitude. Thus, the marginal external cost may be infinite. This would agree with the implicit view of Verhoef (2001a, 2003) and others, eg Small and Chu (2003). However, the above expression is finite when there are sufficient adjacent periods of ordinary congestion. The expression is limited to a finite level as there exist periods in which the elasticity is less than one in magnitude and, thus, there is spare road capacity to allow the further rounds of congestion to become smaller rather than larger. This effect is easily visible in data for Central London (see Figure 4.3.2 later in this Chapter) where for the chosen roads nearly all daytime travel is hypercongested but most of the night-time travel takes place in conditions of ordinary congestion, i.e. the elasticity of speed with respect to density is less than one in magnitude.

The expression for the marginal effect of lost distance costs can be normalised by division by the distance travelled by the new road user $dD\,V\,dt$. This gives a lost distance measure of the marginal external congestion cost of

$$|\varepsilon_{VD}| \left(1 + |\varepsilon_{VD}| + |\varepsilon_{VD}|^2 + \ldots\ldots\right) \tag{4.2.3}$$

In general, it is difficult to translate this measure into a time or money measure of the marginal external congestion cost as this requires knowledge of the traffic speeds and conditions applying when the lost distances are made up so as to give completed journeys and the elasticity, speed and densities are likely to vary across time. An oversimplifying but still useful exploratory assumption is to take these speeds as the same as when the additional road user travelled.[1] Thus, the time cost and money cost of the marginal external congestion are (see the term *b* in equation 3.2.2)

$$b \quad |\varepsilon_{VD}| \quad \frac{1 + |\varepsilon_{VD}| + |\varepsilon_{VD}|^2 + \ldots\ldots}{V} \qquad (4.2.4)$$

This correct expression for the hypercongestion externality can be compared to the traditional money measure of the marginal external congestion cost (with the latter being a commonly agreed incorrect or difficult to understand expression for the hypercongestion externality)

$$b \quad |\varepsilon_{VD}| \quad \frac{1 + |\varepsilon_{VD}| + |\varepsilon_{VD}|^2 + \ldots\ldots}{V} \quad \textit{versus} \quad b \quad \frac{dV}{dF} \quad \frac{F}{V^2} \qquad (4.2.5)$$

In the context of hypercongestion, *dV/dD* is always negative but the derivative *dV/dF* is positive. This positive derivative, explains the odd implication of the conventional economic analysis of hypercongestion of a positive externality for hypercongestion (Walters, 1961; Johnson, 1964 and Newbery, 1987 and 1989).

In Chapter 3, the relation between the flow and density derivatives and elasticities is derived and the result is repeated below.

$$\frac{dV}{dF} = \frac{dV}{(dD\ V + dV\ D)} = \frac{1}{V} \ \frac{dV}{dD} \ \frac{1}{\left(1 + \varepsilon_{VD}\right)} \qquad (4.2.6)$$

Thus,

[1] This assumption is not correct as one would expect further hypercongestion to reduce speed.

$$\frac{\varepsilon_{VD}}{(1 + \varepsilon_{VD})} = \varepsilon_{VF} \quad or \quad \varepsilon_{VD} = \frac{\varepsilon_{VF}}{1 - \varepsilon_{VF}} \tag{4.2.7}$$

The equation (4.2.7) explains how a positive elasticity of speed with respect to flow is compatible with a negative dV/dD and a negative elasticity ε_{VD} greater than one in magnitude. In turn, expressions (4.2.6) and (4.2.7) show how a positive elasticity of speed with respect to flow requires a negative elasticity ε_{VD} greater than one. Thus, the lower arm of figures such as 3.2.1 must be convex. Importantly, the previous expression (4.2.6) and (4.2.4) show how a positive slope of speed against flow relationship, $dV/dF > 0$, is compatible with a negative external effect.

The equation (4.2.4) and the second part of (4.2.7) provide a means of estimating the marginal external hypercongestion cost even though the derivative dV/dD or ε_{VD} are not directly observable. This follows from the derivative dV/dF and elasticity $(dV\ D)/dF$ both being observable from empirical data.

However, it should be noted that assumption of a constant speed, see the speed term in expression (4.2.4), leads to an over/underestimation of the marginal external cost of hypercongestion at peak/off-peak hypercongestion density.

The slope of the speed-flow curve in hypercongestion has an impact on the marginal external cost that may appear counterintuitive. If the slope of the relation between speeds and flows is high and density is high (as would be expected in the circumstances of bottleneck hypercongestion) then the elasticity of speed with respect to flow (the product of these two variables) is also high. Thus, by expression (4.2.7), the elasticity of speed with respect to density is close to one. As this density is the building block of the expression for the marginal external hypercongestion cost in expression (4.2.4), the actual aggregate marginal external hypercongestion cost is lower than otherwise. By contrast, if there is roughly a proportional relationship between speeds and flows, as depicted in the hypothetical lower arm of Figure 3.2.1, then the related elasticity is slightly greater than one and the consequent elasticity of speed with respect to density is very high. This means that the marginal external hypercongestion time cost is large because of the explosive effect of a high elasticity of speed with respect to density, see equation (4.2.4).

In conclusion, it should be repeated that the equation (4.2.7) is of importance as it provides a means of estimating the marginal external hypercongestion cost even though the derivative dV/dD and ε_{VD} are not directly observable.

4.3 Empirical Investigation of Hypercongestion in Central London

4.3.1 Issues in the Investigation of Hypercongestion in Central London

The empirical investigation of hypercongestion starts from the assumption that it is density that it is the cause of hypercongestion. Before the data and econometric investigation are conducted, it is important to consider a number of issues. The first issue is to consider the appropriate manner in which to relate traffic speeds and flows. The second issue examines the types of roads on which to base the empirical investigation. The third is how to separate the data between conditions of ordinary and hyper congested flow. The fourth is to consider simple and non-linear relationships between traffic speeds and flows. These issues were considered in the third section of Chapter 3 and those aspects that were considered there and are identical in the case of hypercongestion are not repeated here. For aspects of these issues which are specific to hypercongestions, further analysis is given here.

The issue of the appropriate specification of dependent and independent variables is of even more importance in the case of hypercongestion. If there is bottleneck congestion, the hypercongested relation between speeds and flows is represented by a vertical line on the speed-flow diagram. In the case of error in the measurement of the flow variable, OLS will result in a horizontal relation, the opposite of the underlying relation. Thus, it is appropriate to regress the flow variable on the speed variable in the search for a bottleneck relationship between speeds and flows. For Central London data, there is clear evidence of a bottleneck relation between speeds and flows where the flow rate is maintained at the maximum level but speeds vary from very low to high. This phenomenon may reflect an effective traffic management which successfully utilizes the traffic facility at the highest vehicle-kilometre capacity per hour.

The important omission of appropriate dependent variables in the study of congestion is not pursued directly in the thesis but is raised as a problem in the study of traffic speeds and flows.

It is suggested that it is important to analyse the hypercongestion relationship between traffic speeds and flows on both urban and trunk/motorway roads. Thus, hypercongestion on both urban London roads and the Chalerm Mahanakorn Expressway in Bangkok is investigated. A variety of urban London roads are examined for which data on flows and speeds are available. It is important that the flow and consequent speed data are collected at points that can be considered to refer to road segments where traffic conditions can be considered to be representative and not unduly affected by nearby traffic lights, intersections, narrowing/widening of roads, entries, exists, etc.

The data also need to be carefully separated out between what is considered to be ordinary congested and hypercongested flow. It is important that a turning point is identified that gives the maximum flow. This can only be achieved through observation of the data and making a judgment that is tested for robustness by examining alternative choices.

Regression models are estimated on all data sets for non-parametric, simple linear, logs, quadratic in logs, and spline relationships between speeds and flows. It is clear from the theory and past evidence that the relation between speeds and flows may be highly non-linear. The data are also pooled to give more efficient estimation and appropriate restrictions are tested for. All estimated specifications have appropriate diagnostic tests conducted.

4.3.2 Data Description

We investigate speed-flow relationships of cars on a variety of street types in the London Congestion Charging Scheme Area. The initial streets and data set was as that used in Chapter 3 and many of the technical details and data choices are the similar between the investigations. These details can be found in the Appendix to Chapter 3. Where differences exist between the two investigations these are made clear immediately below.

The diagrams of speed-flow relationships are illustrated in Figure 4.3.1 for the seven working days in September 2008. All of the relationships are undoubtedly different from Figure 2.2.1. For Albert Embankment, there appears to be no or little hypercongestion and this street was not used in the further analysis. At first glance, it is difficult to interpret the basic data. However, taking London Bridge North and South one can detect an underlying relationship between speeds and flows. At low flows, there is initially a negative relationship and afterwards, at a not well determined flow, there is nearly a vertical drop but considerable noise in the flow measurements around this drop. Closer inspection of the other diagrams also suggests similar relationships. It is possible, by eye, to suggest borderlines between these two different features (as shown in Figure 4.3.1) at 600, 700, 2000, 1210, 1120, 750, and 700 vehicles per hour on Blackfrairs Bridge (North and South), Park Lane (North), Embankment (East and West) and London Bridge (North and South), respectively. These borderlines neatly divide up the data and other borderlines do not. The top and bottom right quadrants of each scatter-plot in Figure 4.3.1 are very similar. This suggests that the observations with speeds above 30 km/h[2] in the top-right quadrant are in hypercongested conditions. The possible borderline around 30 km/h is tested later by SPLINE estimation with a knot at 30 km/h. A few extreme outlier observations are removed on the basis of judgement.

To avoid confusion with any night time hyperconngestion, we deliberately investigate the speed-flow observations during hours with day-light, starting from

[2] km/h stands for kilometres per hour.

6.30 a.m. to 19.00 p.m. We, therefore, use these data (after removing likely ordinary congestion and extreme observations) for our further analysis.

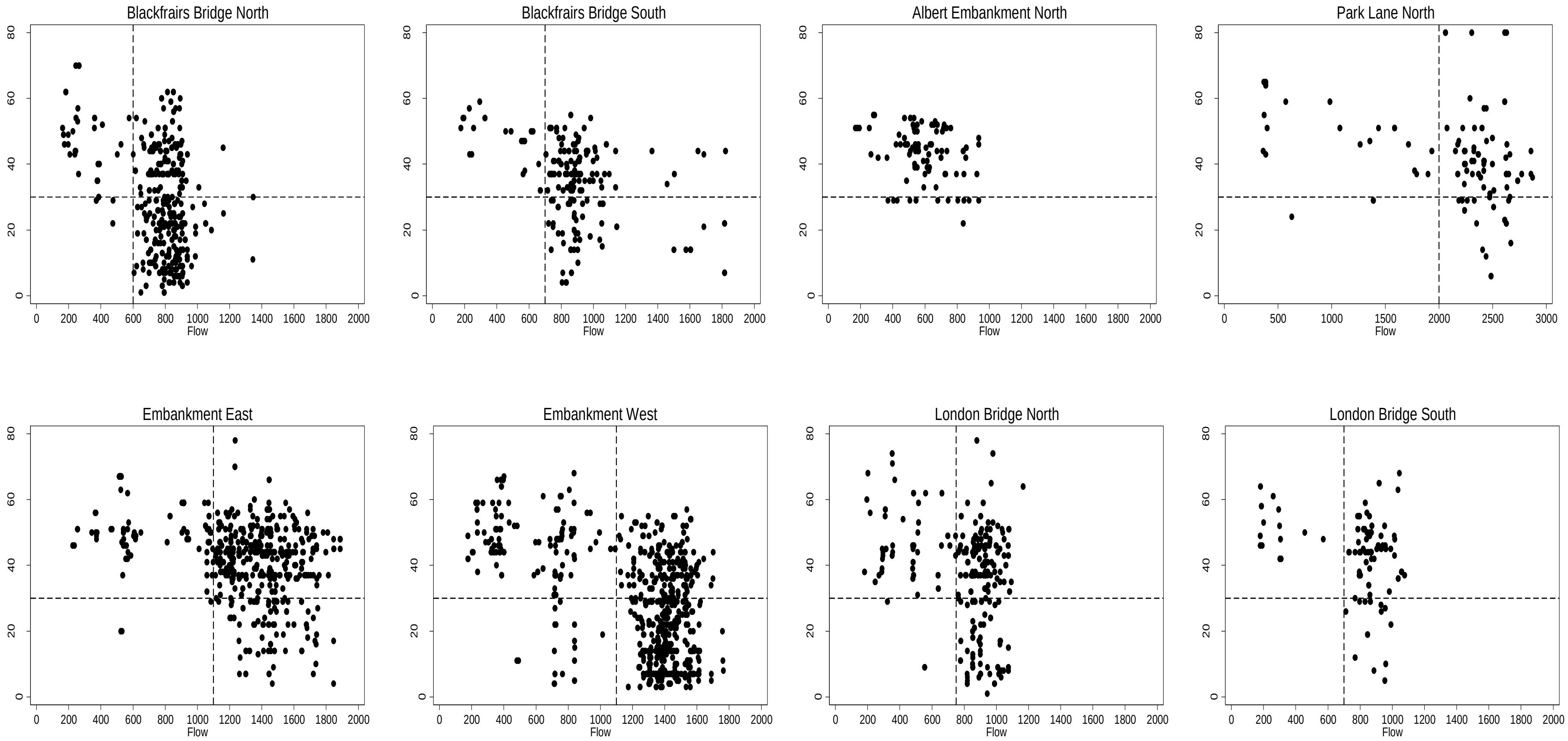

Figure 4.3.1 Speed-Flow Observations on Eight Streets in Central London (24 hours)

It is perhaps possible to explain the common characeteristic of hypercongestion in the chosen hypercongested streets in terms of bottleneck congestion. In each street, there is a traffic light system controlling traffic in both directions. Unless the space the other side of traffic lights is blocked, they deliver an approximately fixed number of vehicles for each period of a green light. Thus, from moderate to high density (just short of complete grid lock) traffic lights will control the flow to be approximately constant. However, if vehicles have to queue for exit from a traffic light controlled segment of road, their speed is reduced. In terms of the identity between flow, speed and density, speed is given by

$$V = \frac{F}{D} \tag{4.3.1}$$

Thus, as density rises and with a fixed flow, the speed must fall. Errors in the measurement of variable (both speeds and flows) and random changes in the structure of traffic are likely to contribute to the great variation in speeds and flows observations shown in the data. This simple model and explanation may well explain the form of the speed-flow scatter diagrams in Figure 4.3.2.

In consideration of the remarkably different characteristics between the two parts of the observed speed-flow relationships, the econometric models of these congestion relationships should be investigated separately. The first part is assumed to represent ordinary congestion and was investigated in Chapter 3. The second part is assumed to represent hypercongestion and is investigated in the present Chapter.

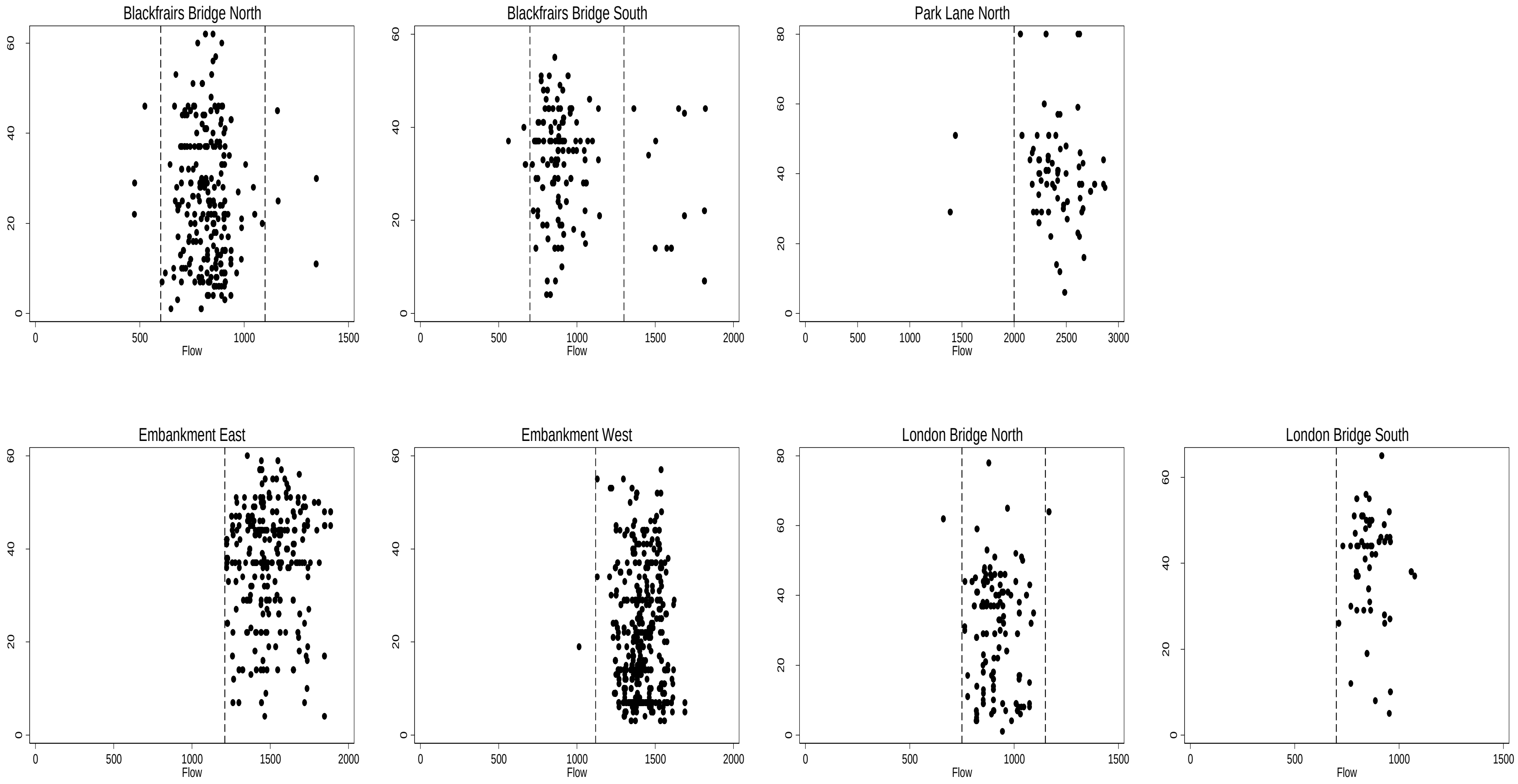

Figure 4.3.2 Speed-Flow Observations on Seven Streets in Central London (day-time hours)

4.3.3 Analysis and Results

Inspection of the scatter diagrams for the seven streets suggests that, for periods of hypercongestion, the relationship between speeds and flows may not be as suggested by Figure 4.1.1. Thus, it is important to consider the causality between speeds and flows, and different specifications of the relationships involved in hypercongestion.

It is the basic argument of this thesis that it is density and road occupation that causes congestion. The two observables are traffic speeds and flows. Density can be directly derived by the identity

$$D = \frac{F}{V} \qquad (4.3.2)$$

It is also argued that the derivative dV/dD is always negative though the sign of the derivative dV/dF depends on whether ordinary or hypercongestion conditions prevail. Thus, it may be thought that analyzing the relation between speed and the derived variable density may be of statistical interest. However, it is odd to regress, for example, speed on the ratio of flow to speed. This is attempting to relate a variable to a manipulated version of this variable. Initial inspection of the data on speed and the derived variable density suggested that this approach may be flawed. In particular, for a hypercongested period on a London street, we suggest that flow was very approximately constant. Thus, regressing speed on density would be the equivalent of regressing speed on its inverse. This indeed appeared to be the outcome of an initial statistical investigation and was rejected as an appropriate approach.

Thus, the traditional approach of relating speed to flow might be followed. It was also of interest to consider the reverse relationship as we consider density, speed and flow to be determined simultaneously. Consequently, there is no obvious reason why flow should not be statistically related to speed rather than vice versa. In particular, as noted previously, econometric investigation of a speed-flow hypercongestion relationship for urban data may confusingly lead to a flat relationship whereas the relation is vertical.

Firstly, we considered simple specifications.

$$F = \chi + \varsigma V + \varepsilon \qquad (4.3.3)$$

Figure 4.3.3 displays Lowess (Locally Weighted Scatterplot Smoothing) of flow-speed relationships on seven streets. These diagrams suggest a flat flow-speed relationship on every street. These suggested speeds are not related to any change in flow and vice versa. However, we carry the analysis further and apply a simple linear regression to examine the flow-speed relations. The results and diagnostic statistics are reported in Table 4.3.1. The results suggest three of the slope coefficients are statistically significantly different from zero. In addition, only two of the slope coefficients are positive thereby satisfying the traditional view of hypercongestion. No regression passed the Normality Test whereas two and one failed the RESET and White Tests, respectively. Nonetheless, all the regressions passed the Heteroscedasticity test. In addition to the regressions, we draw predicted flows and display them in Figure 4.3.4. All of them give nearly flat lines.

Next, we adjust the specification by aggregating all observations of seven streets into a single data set. In order to check whether we can use the same model for seven streets, we add intercept and slope dummy variables. In addition to the diagnostic tests, we test equality in each of the intercept and slope terms. The results in Table 4.3.2 shows that the two hypotheses of equality in intercept and slope terms are rejected. The results of Table 4.3.1 and 4.3.2 are the same indication, there is no [or little] statistically or quantitatively significant relationship between speeds and flows.

Table 4.3.1 Linear Flow-Speed Specifications: Dependent Variable *F*

Variables	BFBN	BFBS	PKLN	EMBE	EMBW	LDBN	LDBS
Constant	836.509***	875.041***	2531.589***	1462.278***	1399.136***	925.752***	941.952***
	(89.20)	(37.67)	(47.50)	(51.95)	(180.38)	(69.91)	(53.04)
V	-0.648**	-0.043	-2.557**	0.284	0.054	-0.413	-1.159***
	(-2.11)	(-0.06)	(-2.04)	(0.40)	(0.18)	(-1.08)	(-2.94)
Diagnostic Statistics							
Observations	327	177	101	394	565	178	70
F-Statistics	4.44	0.00	4.18	0.00	0.03	1.17	3.74
Adjusted R^2	0.010	0.005	0.030	0.002	0.001	0.000	0.038
Heteroscedasticity :Chi-Squared	1.26	0.10	0.89	0.00	0.37	1.76	0.01
	(0.26)	(0.75)	(0.34)	(0.95)	(0.54)	(0.18)	(0.92)
White Test:Chi-Squared	4.12	3.14	1.539	0.17	0.77	2.7	5.88
	(0.12)	(0.20)	(0.46)	(0.91)	(0.67)	(0.25)	(0.05)
RESET:F-Statistics	1.34	0.69	0.16	4.44	4.33	0.28	1.33
	(0.26)	(0.56)	(0.95)	(0.00)	(0.00)	(0.83)	(0.27)
Normality:Chi-Squared	24.86	6.46	5.83	9.51	15.53	6.8	8.83
	(0.00)	(0.03)	(0.05)	(0.00)	(0.00)	(0.03)	(0.01)

Notes:

1. BFBN, BFBS, PKLN, EMBE, EMBW, LDBN, and LDBS denote Blackfrairs Bridge North, Blackfrairs Bridge South, Park Lane North, Embankment East, Embankment West, London Bridge North and London Bridge South respectively.
2. ***p<0.01; **p<0.05, and *p<0.10.
3. Any results which failed the White Test, are already adjusted with Heteroscedasticity-Consistency Standard Errors.
4. Figures in parentheses under the coefficients are ‘t-statistics’ and under the diagnostic tests are ‘p-values’.

Table 4.3.2 Linear Flow-Speed Specification: Dependent Variable *F*

Variables	Coefficients
BFBN	836.509***
	(64.58)
BFBS	875.041***
	(31.84)
PKLN	2531.589***
	(76.71)
EMBE	1462.278***
	(71.79)
EMBW	1399.136***
	(151.34)
LDBN	925.752***
	(47.56)
LDBS	941.952***
	(21.18)
BFBN_V	-0.648
	(-1.52)
BFBS_V	-0.043
	(-0.05)
PKLN_V	-2.557***
	(-3.28)
EMBE_V	0.284
	(0.55)
EMBW_V	0.054
	(0.15)
LDBN_V	-0.413
	(-0.73)
LDBS_V	-1.159***
	(-1.09)

Diagnostic Statistics	
Observations	1812
F-Statistics	16132
Adjusted R^2	0.992
Heteroscedasticity :Chi-Squared	242.13
	(0.00)
White Test:Chi-Squared	181.82
	(0.00)
RESET:F-Statistics	0.59
	(0.62)
Normality:Chi-Squared	32.38
	(0.00)
Testing Restrictions: *F-Statistics*	
(1) $H_0 : \chi_1 = \chi_2 = \chi_3 = \chi_4 = \chi_5 = \chi_6 = \chi_7$	562.35
	(0.00)
(2) $H_0 : \varsigma_1 = \varsigma_2 = \varsigma_3 = \varsigma_4 = \varsigma_5 = \varsigma_6 = \varsigma_7$	2.00
	(0.06)

Notes:

1. BFBN, BFBS, PKLN, EMBE, EMBW, LDBN, and LDBS denote Blackfrairs Bridge North, Blackfrairs Bridge South, Park Lane North, Embankment East, Embankment West, London Bridge North and London Bridge South respectively.
2. ***p<0.01; **p<0.05, and *p<0.10.
3. Any results which failed the White Test, are already adjusted with Heteroscedasticity-Consistency Standard Errors.
4. Figures in parentheses under the coefficients are ‘t-statistics’ and under the diagnostic tests are ‘p-values’.

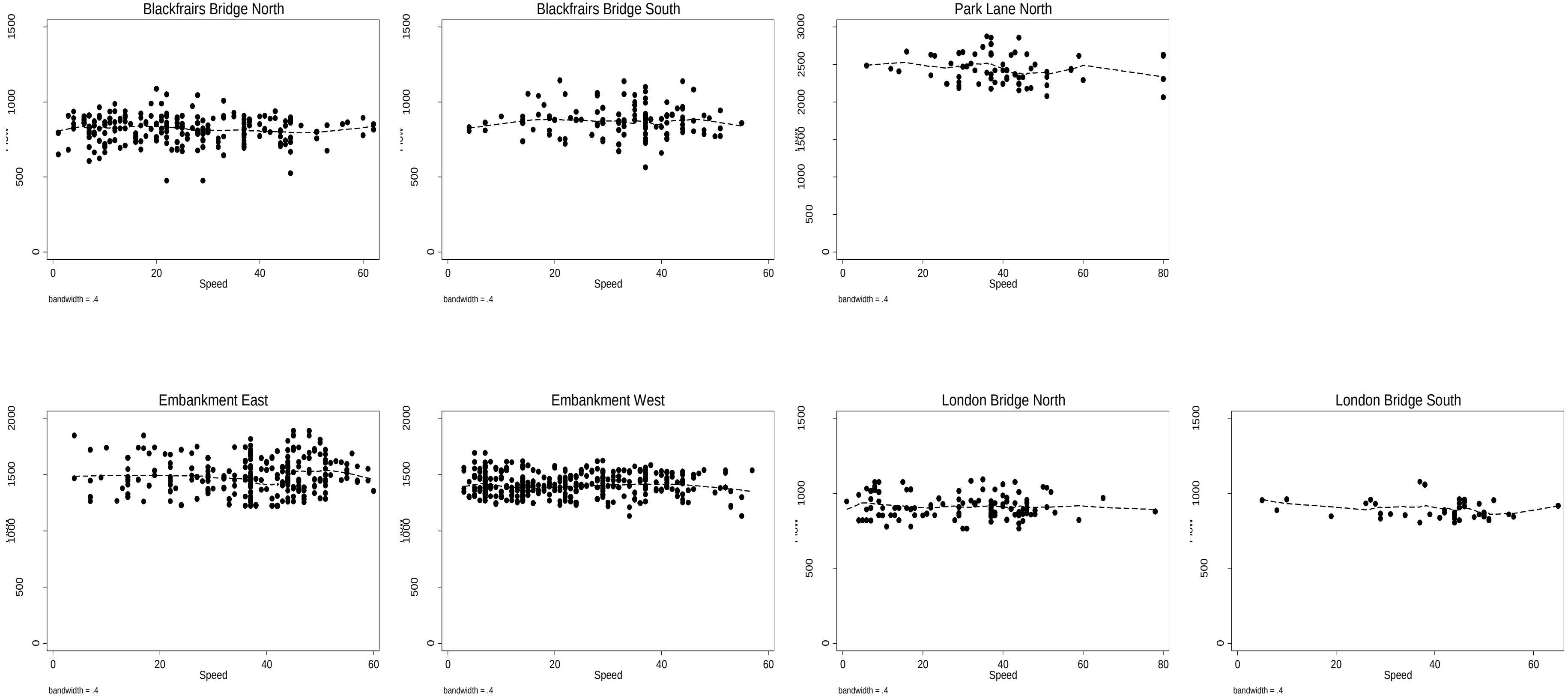

Figure 4.3.3 Flow-Speed Observations [Lowess bandwidth 0.4]

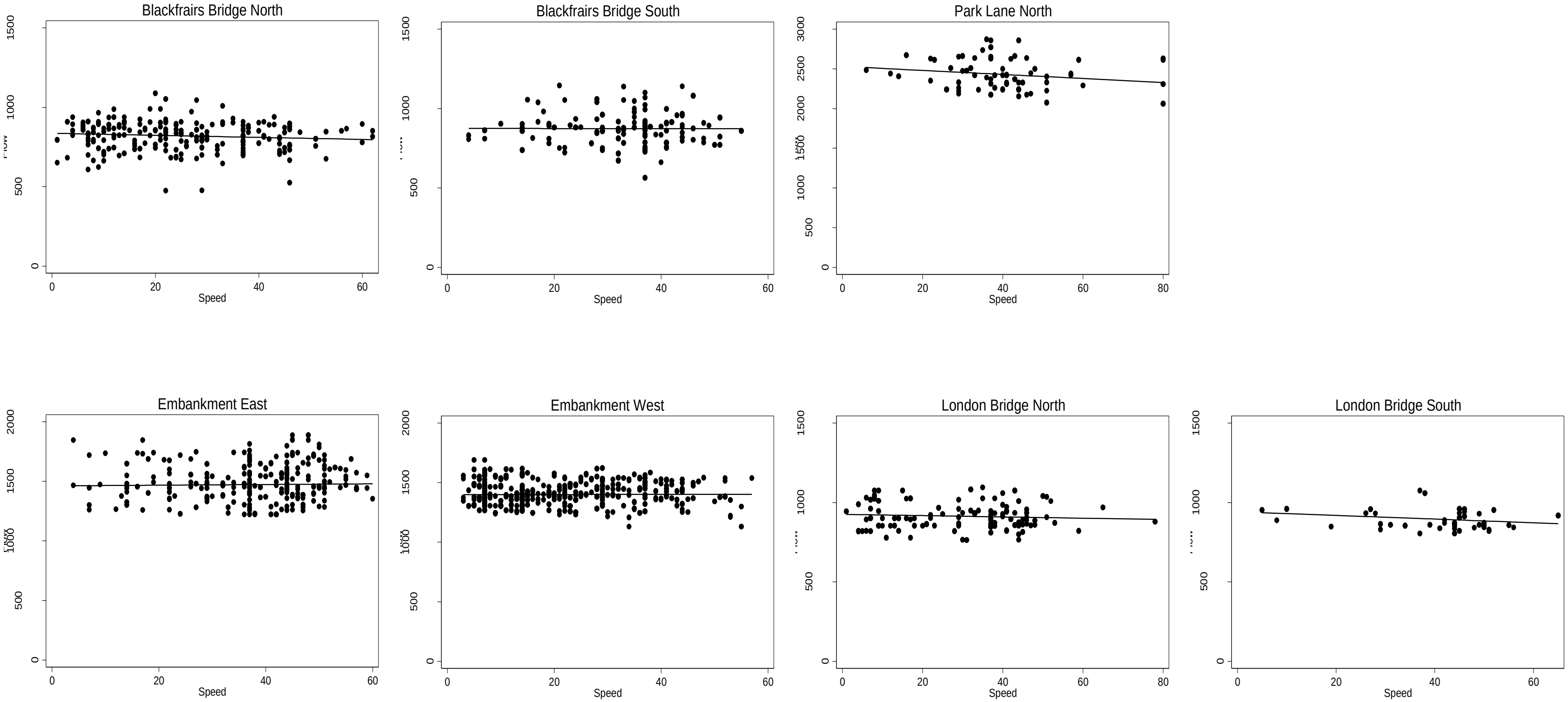

Figure 4.3.4 Flow-Speed Observations with Predicted Flows Corresponding to Table 4.3.1 [F vs V]

We continue the further analysis by using SPLINE to regress (4.3.1) with a knot at 30 km/h. As discussed earlier, the SPLINE knots are set at 30 km/h to investigate whether there is a significant difference between observations with speeds above and below 30km/h at high flows. The results and their diagnostic statistics are displayed in Table 4.3.3. The results show that only one regression had slope coefficients statistically different from zero at 95% level of confidence. None of the regressions passed the Normality Test, whereas one, two and three failed the Heteroscedasticity, White and RESET tests, respectively. Additionally, we report predicted flow to see whether there are any turning–point characteristic at 30 km/h as our assumption; these are demonstrated in Figure 4.3.5. None of the diagrams are close to suggesting a turning point.

Next, we adjust the specification by aggregating all observations of seven streets into a single data set. In order to check whether we can use the same model for seven streets; we add intercept and slope dummy variables. In addition to the diagnostic tests, we test equality in each intercept and slope terms. The results in Table 4.3.4 show that we reject all three hypotheses of equality in intercept and both slope terms. Again, neither Table 4.3.3 nor 4.3.4 indicates no [or little] statistically or quantitatively significant relationship between speed and flow.

Table 4.3.3 SPLINE Flow-Speed Specifications: Dependent Variable *F*

Variables	BFBN	BFBS	PKLN	EMBE	EMBW	LDBN	LDBS
Constant	835.499***	867.064***	2524.658***	1554.533***	1397.67***	932.683***	945.524***
	(67.08)	(25.03)	(21.39)	(33.82)	(140.71)	(53.36)	(46.48)
V1	-0.582	0.346	-2.286	-4.033**	0.162	-0.834	-1.341
	(-0.94)	(0.24)	(-0.53)	(-2.10)	(0.30)	(-1.06)	(-1.18)
V2	-0.730	-0.436	-2.620	2.978***	-0.139	0.030	-1.039
	(-1.00)	(-0.30)	(-1.66)	(2.81)	(-0.16)	(0.0)	(-1.03)
Diagnostic Statistics							
Observations	327	177	101	394	565	178	70
F-Statistics	2.22	0.05	2.07	3.28	0.04	0.77	1.85
Adjusted R^2	0.007	0.01	0.021	0.01	0.003	0.002	0.024
Heteroscedasticity :Chi-Squared	1.58	3.35	0.84	0.35	0.06	0.7	0.01
	(0.20)	(0.06)	(0.35)	(0.55)	(0.81)	(0.40)	(0.91)
White Test:Chi-Squared	3.74	2.79	1.42	6.70	7.56	1.60	5.810
	(0.15)	(0.24)	(0.49)	(0.35)	(0.02)	(0.44)	(0.05)
RESET:F-Statistics	2.16	0.19	0.21	3.00	2.41	0.48	1.68
	(0.09)	(0.90)	(0.89)	(0.03)	(0.06)	(0.69)	(0.17)
Normality:Chi-Squared	24.99	6.32	5.86	13.12	15.27	6.71	9.22
	(0.00)	(0.04)	(0.05)	(0.00)	(0.00)	(0.03)	(0.00)

Notes:

1. BFBN, BFBS, PKLN, EMBE, EMBW, LDBN, and LDBS denote Blackfrairs Bridge North, Blackfrairs Bridge South, Park Lane North, Embankment East, Embankment West, London Bridge North and London Bridge South respectively.
2. ***p<0.01; **p<0.05, and *p<0.10.
3. Any results which failed the White Test, are already adjusted with Heteroscedasticity-Consistency Standard Errors.
4. Figures in parentheses under the coefficients are ‘t-statistics’ and under the diagnostic tests are ‘p-values’.

Table 4.3.4 SPLINE Flow-Speed Specification: Dependent Variable *F*

Variables	Coefficients
BSBN	835.499***
	(48.71)
BFBS	867.064***
	(21.24)
PKLN	2524.658***
	(34.52)
EMBE	1554.533***
	(46.49)
EMBW	1397.67***
	(118.33)
LDBN	932.683***
	(36.55)
LDBS	945.524***
	(14.66)
BFBN_V1	-0.582
	(-0.98)
BFBS_V1	0.346
	(0.30)
PKLN_V1	-2.286
	(-0.85)
EMBE_V1	-4.033**
	(-2.10)
EMBW_V1	0.162
	(0.28)
LDBN_V1	-0.834
	(-1.01)
LDBS_V1	-1.341
	(-1.20)
BFBN_V2	-0.730
	(-1.12)
BFBS_V2	-0.436
	(-0.33)
PKLN_V2	-2.620
	(-1.49)
EMBE_V2	2.978***
	(2.80)
EMBW_V2	-0.139
	(-0.16)
LDBN_V2	0.030
	(0.04)
LDBS_V2	-1.039
	(-1.05)

Diagnostic Statistics	
Observations	1812
F-Statistics	10787.56
Adjusted R^2	0.992
Heteroscedasticity :Chi-Squared	242.84
	(0.00)
White Test:Chi-Squared	188.50
	(0.00)
RESET:F-Statistics	0.39
	(0.67)
Normality:Chi-Squared	28.30
	(0.00)
Testing Restrictions: F-Statistics	
(1) $H_0 : \chi_1 = \chi_2 = \chi_3 = \chi_4 = \chi_5 = \chi_6 = \chi_7$	227.29
	(0.00)
(2) $H_0 : \varsigma_{11} = \varsigma_{12} = \varsigma_{13} = \varsigma_{14} = \varsigma_{15} = \varsigma_{16} = \varsigma_{17}$	1.45
	(0.19)
(3) $H_0 : \varsigma_{21} = \varsigma_{22} = \varsigma_{23} = \varsigma_{24} = \varsigma_{25} = \varsigma_{26} = \varsigma_{27}$	3.05
	(0.00)

Notes:

1. BFBN, BFBS, PKLN, EMBE, EMBW, LDBN, and LDBS denote Blackfrairs Bridge North, Blackfrairs Bridge South, Park Lane North, Embankment East, Embankment West, London Bridge North and London Bridge South respectively.
2. ***p<0.01; **p<0.05, and *p<0.10.
3. Any results which failed the White Test, are already adjusted with Heteroscedasticity-Consistency Standard Errors.
4. Figures in parentheses under the coefficients are ‘t-statistics’ and under the diagnostic tests are ‘p-values’.

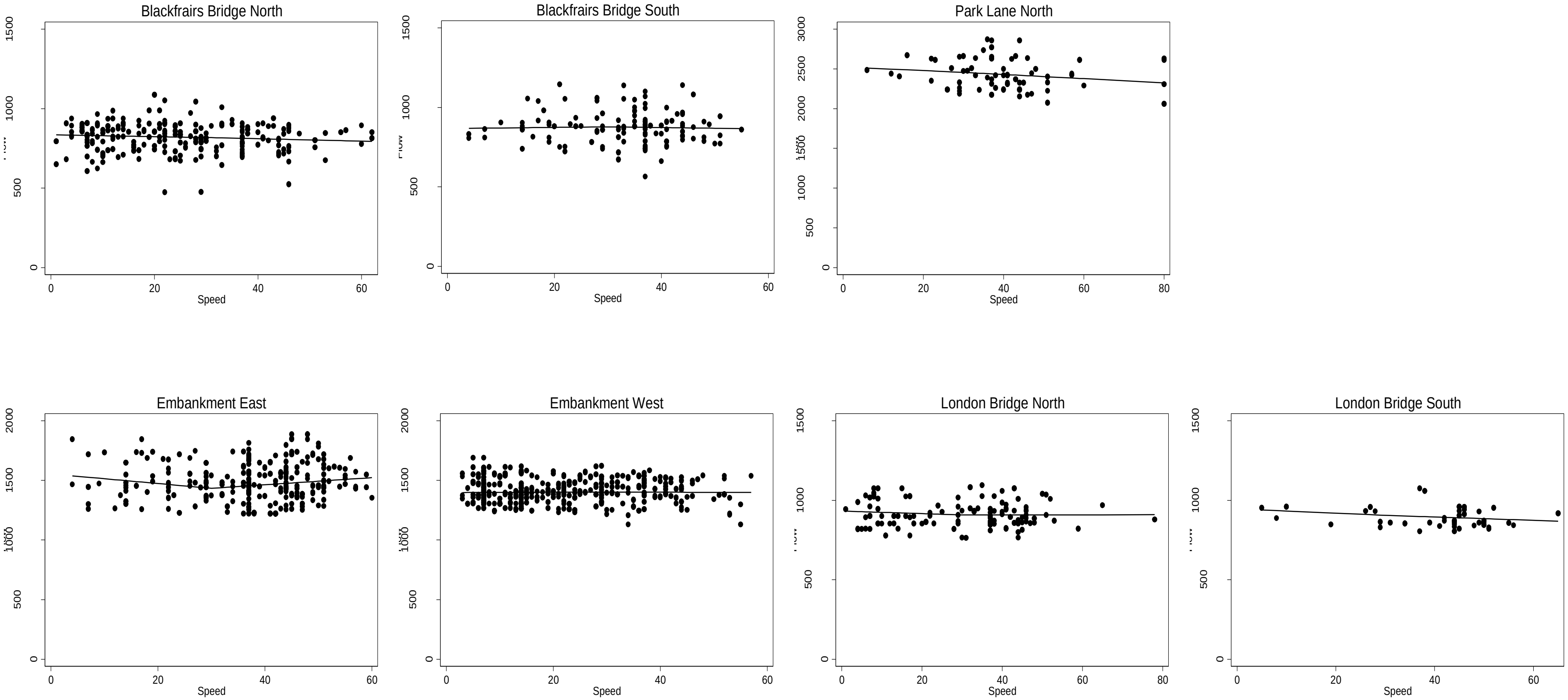

Figure 4.3.5 Flow-Speed Observations with Predicted Flows Corresponding to Table 4.3.3 [F vs V1 V2]

The non-linearity suggested by the theory demands a more complex specification is estimated. We, therefore, proceed to undertake further analysis with the specification.

$$F = \eta + \gamma\, V + \pi\, V^2 + \mu \qquad (4.3.4)$$

The corresponding results and their diagnostic statistics are presented in Table 4.3.5. Only one regression has slope quadratic coefficients statistically significantly different from zero at 99% confidence level. None of them passed the Normality tests whereas only one of them failed the Heteroscedasticity and White Tests. However, five of them passed the RESET test. We report predicted flows and illustrate them in Figure 4.3.6 which shows effectively that relationships between speeds and flows.

Next, we adjust the specification by aggregating all observations of seven streets into a single data set. In order to check whether we can use the same quadratic specification for seven streets, we add seven dummy variables to intercept, slope and curvature terms. In addition to the diagnostic tests, we test equality in each intercept, slope and curvature terms. The results in Table 4.3.6 show that we reject all hypotheses of equality in intercept, slope and curvature terms. Thus, we conclude that there is no [or little] statistically or quantitatively significant relationship between speeds and flows.

In addition to the empirical analyses of seven variety streets in Central London in this Chapter, we also provide similar analyses using SPLINE, simple linear and quadratic specification with logarithm terms in Appendix A4.3. Additionally, we also estimate speed against flow relationships (V vs F) with the same specifications as provided in this Chapter. The results give similar conclusion to those reported in this Chapter. However, as suggested earlier a speed-flow regression of bottleneck hypercongestion is likely to give a flat relationship whilst the underlying relationship is vertical. Thus, the reports of speed against flow estimates are not reported in the main text of this thesis.

In conclusion, not surprisingly, the common characteristic of traffic in hypercongested streets in Central of London appears to be vertical speed-flow relations. This implication of a vertical speed-flow relationship is that the elasticity of speed with respect to density is approximately one.

The analysis of the METC in periods of hypercongestion has been fully covered in the discussion at the end of Chapter 3 where it was assumed that the elasticity of speed with respect to density was one. It is important to repeat that in real world situations, the marginal external cost of hypercongestion is not infinite as there exist adjacent periods of ordinary congestion in which journeys can be completed or started without causing even greater congestion. Additionally, the adjustment of demand to hypercongestion in the short and long run makes a big difference to the METC. In the limit, for ε_{VD} approaching negative one, the METC is the inverse of the product of speed and the demand elasticity ε_{FT}.

Table 4.3.5 Quadratic Flow-Speed Specifications: Dependent Variable *F*

Variables	BFBN	BFBS	PKLN	EMBE	EMBW	LDBN	LDBS
Constant	833.693***	852.310***	2546.46***	1589.078***	1402.072***	931.588***	949.708***
	(56.03)	(19.09)	(24.19)	(29.62)	(104.69)	(49.54)	(23.91)
V	-0.369	1.758	-3.297	-8.677***	-0.269	-0.925	-1.746
	(-0.31)	(0.57)	(0.69)	(-2.62)	(-0.22)	(-0.75)	(-0.73)
V^2	-0.004	-0.030	0.008	0.135***	0.006	0.008	0.008
	(-0.24)	(-0.60)	(0.16)	(2.77)	(0.27)	(0.44)	(0.25)
Diagnostic Statistics							
Observations	327	177	101	394	565	178	70
F-Statistics	2.24	0.18	2.08	3.91	0.05	0.68	0.06
Adjusted R^2	0.007	0.009	0.021	0.014	0.003	0.003	0.024
Heteroscedasticity :Chi-Squared	1.89	4.30	0.92	0.06	0.01	1.09	0.06
	(0.16)	(0.03)	(0.33)	(0.81)	(0.92)	(0.29)	(0.79)
White Test:Chi-Squared	3.24	3.33	1.66	3.00	0.01	1.55	6.41
	(0.19)	(0.18)	(0.43)	(0.22)	(0.99)	(0.45)	(0.04)
RESET:F-Statistics	1.35	0.42	0.47	4.73	4.22	0.58	1.83
	(0.25)	(0.73)	(0.70)	(0.00)	(0.00)	(0.63)	(0.15)
Normality:Chi-Squared	25.11	6.14	5.70	13.86	15.73	6.67	9.58
	(0.00)	(0.04)	(0.05)	(0.00)	(0.00)	(0.03)	(0.00)

Notes:

1. BFBN, BFBS, PKLN, EMBE, EMBW, LDBN, and LDBS denote Blackfrairs Bridge North, Blackfrairs Bridge South, Park Lane North, Embankment East, Embankment West, London Bridge North and London Bridge South respectively.
2. ***p<0.01; **p<0.05, and *p<0.10.
3. Any results which failed the White Test, are already adjusted with Heteroscedasticity-Consistency Standard Errors.
4. Figures in parentheses under the coefficients are 't-statistics' and under the diagnostic tests are 'p-values'

Table 4.3.6 Quadratic Flow-Speed Specifications: Dependent Variable *F*

Variables	Coefficients
BSBN	833.693***
	(40.71)
BFBS	852.310***
	(16.20)
PKLN	2546.246***
	(39.07)
EMBE	1589.078***
	(40.68)
EMBW	1402.072***
	(88.01)
LDBN	931.588***
	(33.85)
LDBS	949.708***
	(13.63)
BFBN_V	-0.369
	(-0.34)
BFBS_V	1.758
	(0.83)
PKLN_V	-3.297
	(-0.86)
EMBE_V	-8.677***
	(-2.57)
EMBW_V	-2.698
	(-0.20)
LDBN_V	-0.925
	(-0.84)
LDBS_V	-1.746
	(-0.94)
$BFBN(V)^2$	-0.004
	(-0.28)
$BFBS(V)^2$	-0.030
	(-0.83)
$PKLN(V)^2$	0.008
	(0.17)
$EMBE(V)^2$	0.135***
	(2.88)
$EMBW(V)^2$	0.006
	(0.26)
$LDBN(V)^2$	0.008
	(0.56)
$LDBS(V)^2$	0.008
	(0.30)

Diagnostic Statistics	
Observations	1812
F-Statistics	10803
Adjusted R^2	0.992
Heteroscedasticity :Chi-Squared	241.62
	(0.00)
White Test:Chi-Squared	187.63
	(1.8×10^{-41})
RESET:F-Statistics	3.81
	0.02
Normality:Chi-Squared	-
	(0.00)
Testing Restrictions: F-Statistics	
(1) H_0: $\eta_1 = \eta_2 = \eta_3 = \eta_4 = \eta_5 = \eta_6 = \eta_7$	193.10
	(0.00)
(2) H_0: $\gamma_1 = \gamma_2 = \gamma_3 = \gamma_4 = \gamma_5 = \gamma_6 = \gamma_7$	1.88
	(0.08)
(3) H_0: $\pi_1 = \pi_2 = \pi_3 = \pi_4 = \pi_5 = \pi_6 = \pi_7$	2.1
	(0.05)

Note

1. BFBN, BFBS, PKLN, EMBE, EMBW, LDBN, and LDBS denote Blackfrairs Bridge North, Blackfrairs Bridge South, Park Lane North, Embankment East, Embankment West, London Bridge North and London Bridge South respectively.
2. ***p<0.01; **p<0.05, and *p<0.10.
3. Any results which failed the White Test, are already adjusted with Heteroscedasticity-Consistency Standard Errors.
4. Figures in parentheses under the coefficients are ‘t-statistics’ and under the diagnostic tests are ‘p-values’.

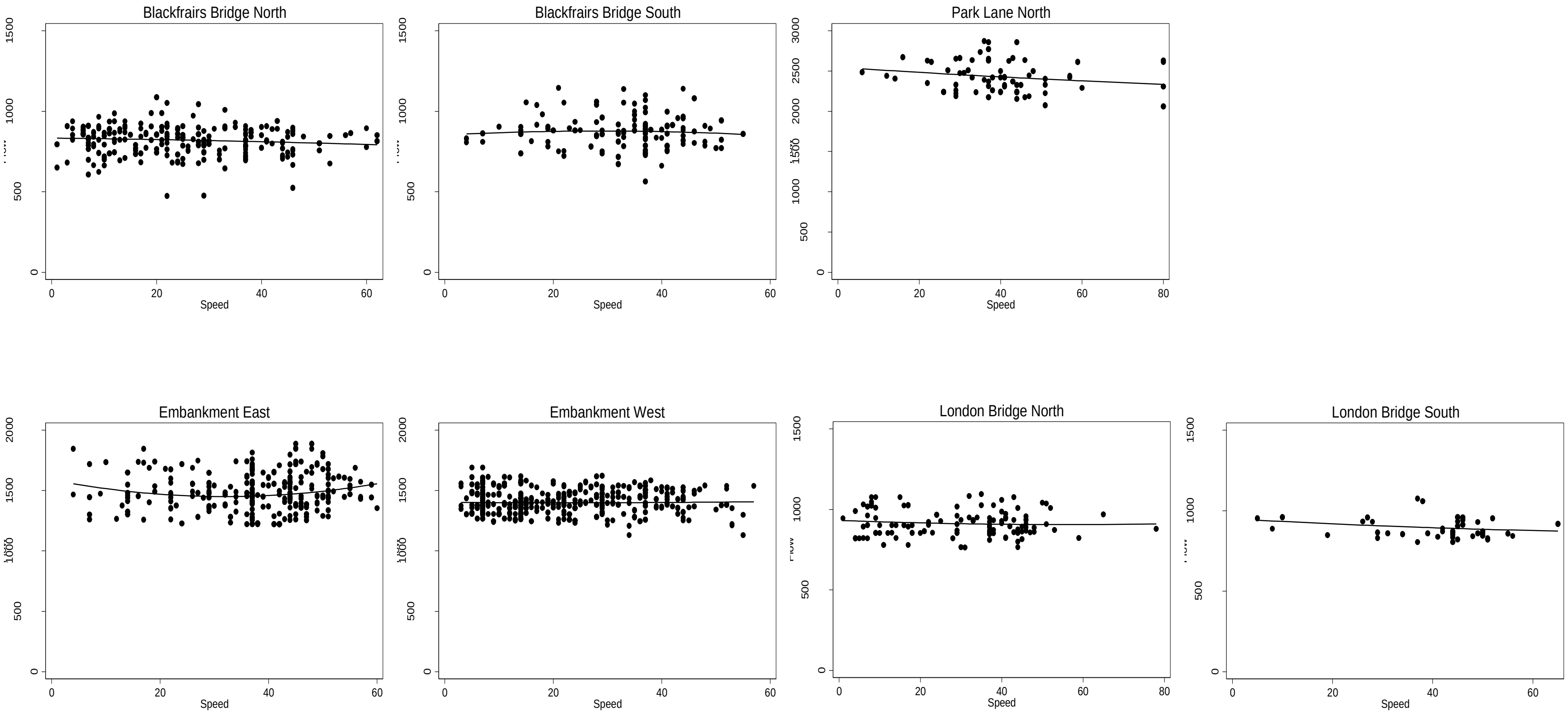

Figure 4.3.6 Flow-Speed Observations with Predicted Flows Corresponding to Table 4.3.6 [F vs V V^2]

4.4 Empirical Investigation of Hypercongestion on The Chalerm Mahanakorn Expressway in Bangkok

As the urban hypercongestion data used in the previous analysis failed to produce a simple textbook relationship between speeds and flows, it is of interest to investigate data for expressway traffic. We investigate the hypercongestion speed-flow relationship of traffic on the Chalerm Mahanakorn Expressway in Bangkok

4.4.1 Data Description

We investigate car speed-flow relationships of three vehicle types on the Chalerm Mahanakorn Expressway in Bangkok for data collected from 7.00 a.m. to 21.00 p.m. over four days, on Tuesday 20th Friday 30th and Saturday 31st July 2010 and on Monday 2nd August 2010.

The collection of speed observations used in this research was a particular study under the Development of EXAT[3] Intelligent Transportation System. This project was developed by the Expressway Authority of Thailand and collected observations of speeds, time periods, locations and fuel consumption using GPS and Vehicle Tracking System technologies to examine the comparison of driving behavior on the expressways (specially operated by the Expressway Authority of Thailand) and the regular ground routes (operated by others, i.e. the Bangkok Metropolitan Administration or the Thailand Department of Highways). Unfortunately, the investigation of traffic flow was not a task of the project. Thus,

[3] EXAT stands for the Expressway Authority of Thailand.

traffic flow data used in this study are taken from the other sources but still supplied by the Expressway Authority of Thailand.

Traffic flow in this study were observed from the total number of toll passes sold in every hour for different vehicle types collected at tollbooths at the first entry point at either end of the Chalerm Mahanakorn Expressway, i.e. Dindaeng and Bangna. Thus, one can determine the flow from the first entry point to the first exit point at each end of the expressway (3 kilometres road length for Dindaeng and 1 kilometre road length for Bangna). There were three vehicles types: four-wheel passenger cars, large and exempt vehicles. We used prices of toll passes to classify type of vehicles because four-wheel passenger cars and large vehicles are charged differently. There was no charge for exempt vehicles. Large vehicles in this study included buses and those vehicles used for transporting goods; i.e. vehicles with 6-wheels, 8-wheels, 10-wheels, and more than-10-wheels. Exempt vehicles included ambulances, fire engines, police cars, diplomatic and official cars, rescue cars and those with parades.

Our study measures the speeds and flows on four and three 100-metre homogenous segments of outbound and inbound road respectively (see Appendix A4.2 for details of the expressway segments). In order to estimate the equilibrium speed-flow relationship, we deliberately choose the speed-flow observations on relatively straight road segments without any immediate pre or post impediments. In addition, these straight road segments are not near the first entry and exit. Thus, our study observes car speeds on four and three 100-metre homogenous segments of outbound and inbound parts of the expressway respectively. The speeds used in this research were reported by GPRS on floating cars working for the Expressway Authority of Thailand. The GPRS monitoring reported approximately 4,700 speed observations per hour or almost 78 observations per minutes. The coordinates of these road segments were worked out by observing the latitude and longitude decimal points (locations of Dindaeng and Bangna Toll booths, their road characteristics and the respective first exits) on a map provided on Google Earth. Google Earth permits us to measure a near exact distance from each automatic counter and to identify the decimal latitude and longitude of each location. This information enabled us to define the rectangular boundary of each road segment of 100 metres and an expressway width by latitude and longitude decimal points. Because GPRS monitoring reports each speed observation with latitude and longitude decimal points, we, therefore, were able to capture cars' speed observations in these rhomboids.

As discussed earlier, flows were observed every hour, whereas many speeds were observed at one moment in time. Therefore, we develop a simple method to measure average speed over each segment and flow is calculated through interpolation of the flow data to the average time of the speed measurements and allowing for the time taken to arrive at the different expressway mid-segments.

The scatter diagram in Figure 4.4.1 shows the speed-flow relationship by using a factor of 2 PCE[4] to convert the number of large vehicles and exempt vehicles into a standard unit. The later statistical analysis reports results from data using PCE factors of both one and two. These flows are then added to the corresponding flows of four-wheel passenger cars. These observations show both ordinary and

[4] 2 PCE is a factor which is commonly recommended for converting the impact of a heavy vehicle as an impact of two passenger cars, see review in Section 2.8, Chapter 2.

hypercongestion. A clear distinction between ordinary congestion and hypercongestion occurs at approximately 40 km/h. Speeds lower than 40 km/h represent approximately 19% of the total observations. The present empirical analysis is concerned only with hypercongestion therefore the speed observations more than 40 km/h are removed. Thus, a speed-flow scatter diagram for hypercongestion is shown in Figure 4.4.2. The diagram clearly suggests a positive convex speed-flow relationship. All regressions are reported for flows calculated using a weighting of one and two for passenger car equivalents for trucks, buses and exempt vehicles.

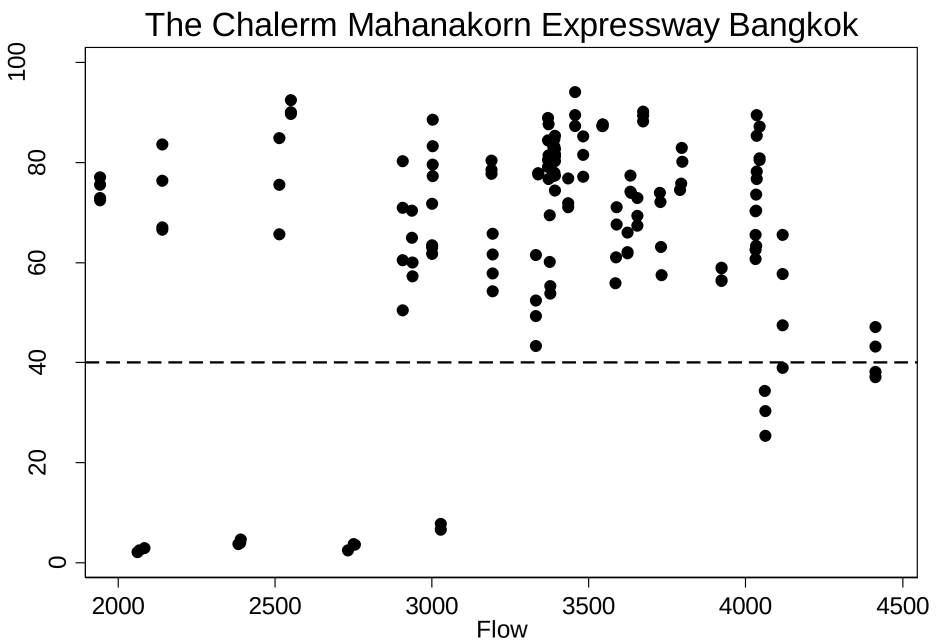

Figure 4.4.1 Speed-Flow Relationship on the Chalerm Mahanakorn Expressway in Bangkok (all observations)

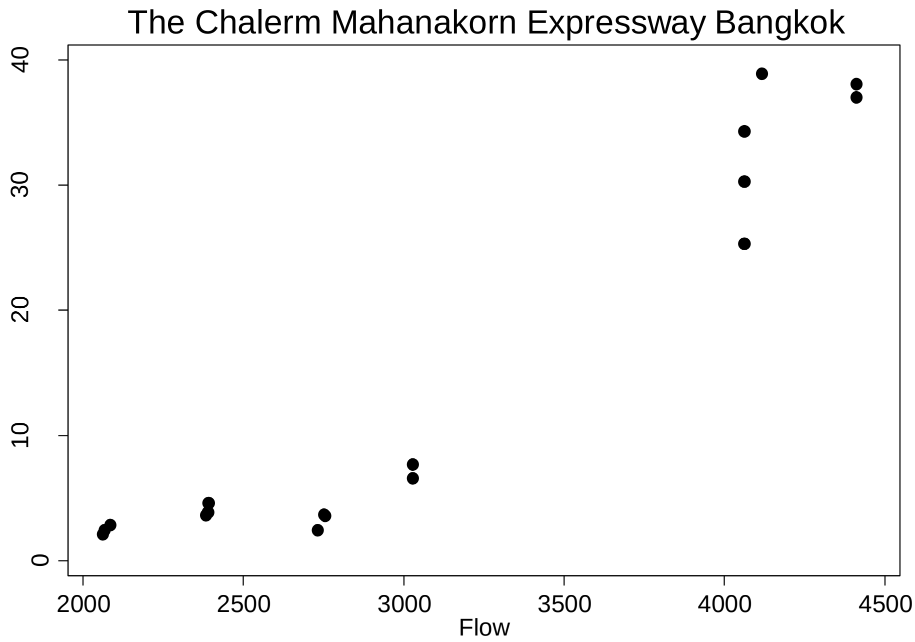

Figure 4.4.2 Hypercongestion Speed-Flow on the Chalerm Mahanakorn Expressway in Bangkok

4.4.2 Analysis and Results

Our research estimates the relationships between speeds and flows using the specification.

$$V = \alpha + \beta F + \varepsilon \qquad (4.4.1)$$

The observations used in this investigation are from two different road segments i.e. outbound and inbound routes of the Chalerm Mahanakorn Expressway in Bangkok. We aggregate all observations into a single data set. In order to check whether we can use the same regression for both road segments, we, therefore, add dummy variables to intercept and slope terms. Correspondingly, the estimations and their diagnostic tests are presented in Table 4.4.1. The results suggest that only outbound slope coefficients in both estimations are statistically significantly different from zero at the 95% confidential level. Nevertheless, all of them give a positive slope which satisfies the conventional view of speed-flow relationships in hypercongestion. However, both regressions failed all diagnostic tests. In addition, we test equalities in intercept and slope terms. Both regressions give the same result of not rejecting the null hypothesis of equality in intercept terms. In contrast, the null hypothesis of equality of slope coefficient terms is rejected. These regressions imply different slope coefficients between outbound and inbound road segments.

The non-linearity suggested in the theory demands that a more complex specification is estimated. We apply a quadratic model.

$$V = \eta + \gamma F + \psi (F)^2 + \mu \tag{4.4.2}$$

The estimated results and diagnostic tests are reported in Table 4.4.1. All coefficients of outbound are statistically significantly different from zero, but inbound coefficients are not. All regressions failed all diagnostic tests. After applying the restriction of equalities of intercept and slope coefficient terms, the results suggest rejection of both null hypotheses. These imply coefficient and slope terms are different between outbound and inbound road segments.

Next, we estimate the elasticity of speed with respect to flow with two log specifications. Firstly, we apply a log specification.

$$lnV = \tau + \xi lnF + \upsilon \tag{4.4.3}$$

These estimations have been undertaken in a same style as the previous analyses. The estimations and their diagnostic tests are reported in Table 4.4.2. Both estimations yield positive slopes which satisfy the conventional view of hypercongestion. However, only outbound slope coefficients are statistically significantly different from zero at 99% level of confidence. Both regressions passed the Heteroscedasticity and White tests but failed the RESET and Normality tests. In addition, we test equalities in each intercept and slope terms. Both regressions give the same results. They accept the null hypothesis of equality in intercept terms and reject the equality in slope coefficient terms. These imply different slope coefficients between outbound and inbound road segments.

Secondly, we regress a quadratic in logs model (4.4.4)

$$lnV = \varphi + \pi \, lnF + \lambda \, (lnF)^2 + \delta \qquad (4.4.4)$$

Table 4.4.2 illustrates the quadratic in logs specifications using (4.4.4) and their diagnostic tests. The results suggest that none of the coefficients are statistically significantly different from zero. Moreover, they failed almost all diagnostic tests, but passed the RESET test. After testing equality in intercept and slope coefficient terms, they suggest similar results as using (4.4.3) explained above. Thus, we adjust the regression and tests of the restrictions as shown in Table 4.4.2 suggests the best solution of equal intercept, slope and curvature terms. Therefore, we estimate predicted speeds and present the results in Figure 4.4.3 (the predicted values for actual flows are joined by linear lines).

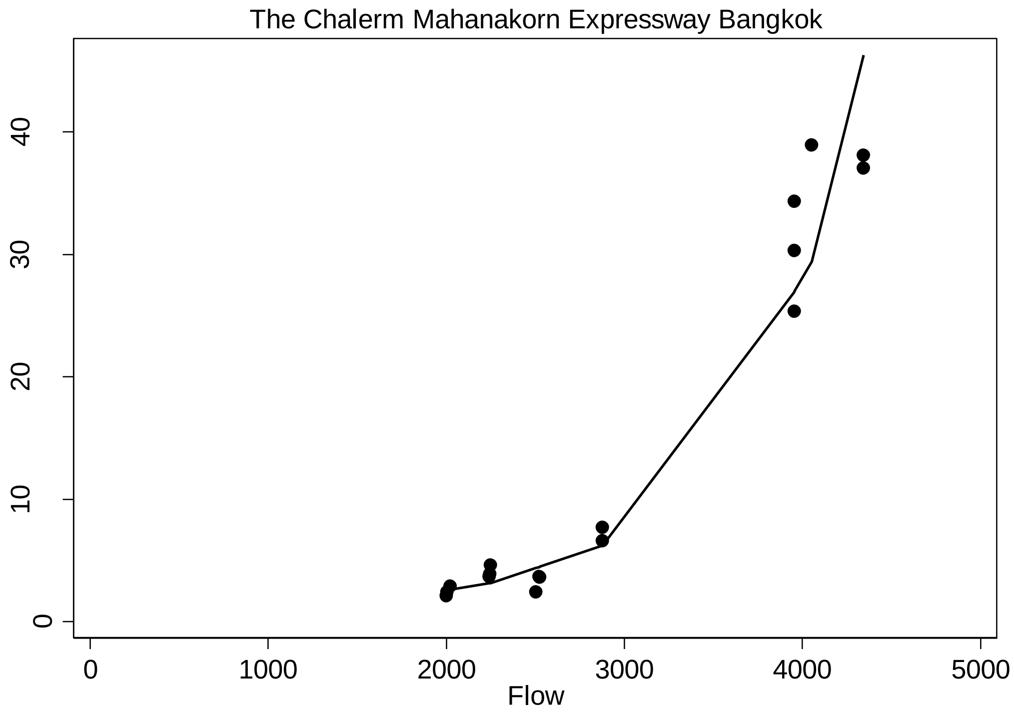

Figure 4.4.3 Log Quadratic Speed-Flow Relationships on the Chalerm Mahanakorn Expressway in Bangkok corresponding to the results in Table 4.4.2, using a factor of 2 PCE to convert number of trucks and exempt vehicles: lnV vs lnF $(\ln F)^2$

Table 4.4.1 Hypercongestion Speed-Flow Specifications: Dependent Variable *V*

	V vs F		V vs F F^2	
Variables	1 PCE	2 PCE	1 PCE	2 PCE
Outbound	-38.372	-41.483	-4281.225***	-8320.496***
	(-1.50)	(-1.38)	(-3.42)	(-3.34)
Inbound	-6.627	-5.088	28.714***	28.613***
	(-1.05)	(-0.82)	(3.44)	(3.36)
Outbound_F	0.017	0.018**	2.065***	3.927***
	(2.83)	(2.51)	(3.46)	(3.36)
Inbound_F	0.004	0.003	-0.025	-0.023
	(1.69)	(1.47)	(-1.41)	(-1.23)
Outbound_F^2			-2.46×10^{-4}***	-4.60×10^{-4}***
			(-3.47)	(-3.37)
Inbound_F^2			6.08×10^{-6}	5.37×10^{-6}
			(1.65)	(1.41)
Diagnostic Statistics				
Observations	17	17	17	17
F-Statistics	252.17	226.57	264.58	247.24
Adjusted R^2	0.983	0.981	0.989	0.988
Heteroscedasticity :Chi-Squared	8.48	7.90	5.16	4.17
	(3.6×10^{-3})	(5.0×10^{-3})	(0.02)	(0.40)
White Test:Chi-Squared	7.19	7.27	8.07	8.22
	(0.02)	(0.02)	(0.01)	(0.01)
RESET:F-Statistics	3.80	4.49	87.18	98.08
	(0.04)	(0.03)	(0.00)	(0.00)
Normality:Chi-Squared	5.05	5.09	6.42	5.60
	(0.08)	(0.07)	(0.04)	(0.06)
Testing Restrictions:				
(1) $\alpha_1=\alpha_2$ or $\eta_1=\eta_2$	1.45	1.41	8.98	9.68
	(0.24)	(0.25)	(0.01)	(9.9×10^{-3})
(2) $\beta_1=\beta_2$ or $\gamma_1=\gamma_2$	3.79	3.62	9.05	9.71
	(0.07)	(0.07)	(0.01)	(9.8×10^{-3})
(3) $\psi_1=\psi_2$			9.07	9.72
			(0.01)	(9.8×10^{-3})

Notes: (1) ***p<0.01; **p<0.05, and *p<0.10. Figures in parentheses under the coefficients are 't-statistics' and under the diagnostic tests are 'p-values'. (2) Any results which failed the White Test, are already adjusted with Heteroscedasticity-Consistency Standard Errors.

Table 4.4.2 Hypercongestion Speed-Flow Specifications: Dependent Variable *lnV*

	lnV vs lnF		lnV vs lnF $(lnF)^2$		lnV vs lnF $(lnF)^2$		lnV vs lnF $(lnF)^2$		lnV vs lnF $(lnF)^2$	
Variables	1 PCE	2 PCE	1 PCE	2 PCE	1 PCE	2 PCE	1 PCE	2 PCE	1 PCE	2 PCE
Constant									143.692*	226.614***
									(1.97)	(2.93)
Outbound	-15.375	-16.248	-	-	286.398	235.437	18.988	48.202		
	(-0.80)	(-0.70)	(-)	(-)	(0.82)	(0.65)	(0.16)	(0.34)		
Inbound	-17.339***	-14.734***	253.468	209.818	245.680	205.6942	18.237	47.286		
	(-3.96)	(-3.37)	(0.72)	(-0.61)	(0.82)	(0.65)	(0.15)	(0.33)		
lnF							-6.706	-13.793	-39.212**	-59.919***
							(-0.22)	(-0.38)	(-2.15)	(-3.11)
Outbound_lnF	2.271	2.369	-1.417	-1.518	-70.182	-57.901				
	(0.99)	(0.85)	(-0.74)	(-0.61)	(-0.84)	(-0.67)				
Inbound_lnF	2.400***	2.049***	-67.251	-55.419	-65.249	-54.363				
	(4.25)	(3.67)	(-0.75)	(0.64)	(-0.84)	(-0.67)				
$(lnF)^2$					4.348	3.608	0.582	1.011	2.687**	3.976***
					(0.87)	(0.70)	(0.30)	(0.43)	(2.36)	(3.31)
$Outbound\_(lnF)^2$			0.221	0.232						
			(0.77)	(0.63)						
$Inbound\_(lnF)^2$			4.477	3.675						
			(0.77)	(0.59)						
Diagnostic Statistics										
Observations	17	17	17	17	17	17	17	17	17	17
F-Statistics	416.33	352.69	377.99	271.49	326.83	414.82	419.09	357.47	171.77	141.29
Adjusted R^2	0.989	0.988	0.989	0.987	0.989	0.991	0.989	0.988	0.955	0.946
Heteroscedasticity :Chi-Squared	1.45	1.25	2.05	1.70	2.04	1.70	1.40	1.29	0.31	0.25
	(0.22)	(0.26)	(0.15)	(0.19)	(0.15)	(0.19)	(0.23)	(0.25)	(0.57)	(0.62)
White Test:Chi-Squared	2.76	4.33	1.84	2.83	1.83	2.83	2.47	3.83	0.46	0.69
	(0.25)	(0.11)	(0.39)	(0.24)	(0.39)	(0.24)	(0.29)	(0.14)	(0.79)	(0.70)
RESET:F-Statistics	7.92	10.71	9.08	11.33	6.79	9.14	7.59	8.28	4.97	7.92
	(5.4×10^{-3})	(1.8×10^{-3})	(4.4×10^{-3})	(2.1×10^{-3})	(8.9×10^{-3})	(3.3×10^{-3})	(6.23×10^{-3})	(3.7×10^{-3})	(0.02)	(4.3x10-3)
Normality:Chi-Squared	5.07	4.53	2.35	3.09	2.36	3.09	4.35	3.90	2.14	1.85
	(0.07)	(0.10)	(0.30)	(0.21)	(0.30)	(0.21)	(0.11)	(0.14)	(0.34)	(0.39)
Testing Restrictions:										
(1) $\tau_1 = \tau_2$ or $\varphi_1 = \varphi_2$	0.01	0.00	0.70	0.44	0.69	0.97	1.70	2.13		
	(0.92)	(0.94)	(0.41)	(0.51)	(0.42)	(0.34)	(0.21)	(0.16)		
(2) $\xi_1 = \xi_2$ or $\pi_1 = \pi_2$	9.52	7.09	0.71	0.44	0.67	0.94				
	(2.8×10^{-3})	(8.3×10^{-3})	(0.41)	(0.51)	(0.42)	(0.35)				
(3) $\lambda_1 = \lambda_2$			0.72	0.44						
			(0.41)	(0.51)						

Notes: (1) ***p<0.01; **p<0.05, and *p<0.10. Figures in parentheses under the coefficients are 't-statistics' and under the diagnostic tests are 'p-values'. (2) Any results which failed the White Test, are already adjusted with Heteroscedasticity-Consistency Standard Errors.

We use parameters from Table 4.4.1 and 4.4.2 to calculate elasticities of speed with respect to flow and density. They are presented in Table 4.4.3. The results show that every regression gives a positive elasticity of speed with respect to flow but a negative elasticity of speed with respect to density. In addition, the magnitudes of elasticity with respect to density are much greater than one.

The results in Tables 4.4.1 and 4.4.2 use data based on the two different possible PCE factors for converting trucks and exempt vehicles into passenger car equivalents. The results and consequent elasticities reported in Table 4.4.3 are close for the two data sets. Thus, we do not distinguish between the two possible PCE factors in the later analysis and simulations.

The following dynamic simulation analysis of the METCs is very similar to that conducted for London and reported in Table 3.3.22. The analysis was constructed on an Excel database and is listed as file CONGSIMUL and under worksheet BANGHYPER. The analysis takes account of the external congestion effect taking place across time and dealing with variation in speeds and size of the congestion effect. The first dynamic effect to note is to allow for the fact that all journeys are a finite distance, we assume that all journeys along the Expressway are of the same average distance at 21 km, which is the reported average trip distance, see Pollution Control Department Thailand (2004). The estimates of the average speed at the hour points in Table 4.4.5 are taken from estimates of the floating car and from approximations for those hours in which floating cars are not used, eg the time from late evening to early morning, . The negative elasticities of speed with respect to density are assumed as 0.1, 0.5, 1.2 and 1.8 respectively during hours of ordinary congestion, the hours immediately before or after periods of hyper congestion, the early hypercongestion period and the late hypercongestion period. The first and last two estimates are justified by the econometric investigation of this Chapter (it is notable that the hypercongestion elasticities are higher than those observed in London hypercongestion). The second estimate is an appropriate guess at the average elasticity between the hours of ordinary congestion and hypercongestion.

Table 4.4.3 Elasticities of Speed with respect to Flow and Density

Outbound Road Route: Hypercongestion on The Chalerm Mahanakorn Expressway in Bangkok

	V vs F		lnV vs lnF		V vs F F^2		lnV vs lnF $(\ln F)^2$	
	ε_{VD}	ε_{VF}	ε_{VD}	ε_{VF}	ε_{VD}	ε_{VF}	ε_{VD}	ε_{VF}
1 PCE	-1.89	2.13	-1.79	2.27	-1.24	5.24	-1.22	5.50
2 PCE	-1.82	2.22	-1.73	2.37	-1.14	8.26	-1.18	6.41

Inbound Road Route: Hypercongestion on The Chalerm Mahanakorn Expressway in Bangkok

	V vs F		lnV vs lnF		V vs F F^2		lnV vs lnF $(\ln F)^2$	
	ε_{VD}	ε_{VF}	ε_{VD}	ε_{VF}	ε_{VD}	ε_{VF}	ε_{VD}	ε_{VF}
1 PCE	-1.60	2.67	-1.71	2.40	-1.81	2.23	-1.66	2.52
2 PCE	-1.78	2.29	-1.95	2.04	-1.83	2.21	-1.78	2.28

The estimates are constructed with the same methods used for Table 4.3.22 and the details are not repeated here. It might be expected that with no large changes in speed, the impact of this full dynamic analysis would be limited. In particular, for periods of little change in speed and elasticity of speed with respect to density, the conventional and new methods of estimating the METC differ by little. Thus, the impacts on estimation of METCs is minimal when allowing for the length of average journey distance, the overlapping of the external effect into other time periods and differences between the very short, short and long run based estimates of the METC. However, as speeds fall markedly and the elasticity approaches (negative) one, the impact of the dynamic analysis becomes important. These outcomes are clearly visible in Table 4.4.4 for the METCs estimated at the hour points.

For periods of hypercongestion, Table 4.4.4 shows the METCs to be high and very much higher at the beginning of a period of hypercongestion. This occurs as when hypercongestion is continuous, the congestion effect is explosive and cannot be dissipated until a period of ordinary congestion is reached. The average journey time of 21km means that the displaced travel occurs at a later distance and time than is the case in London where the average journey is only a shorter 8km. Thus, there is time for fewer cycles of the hypercongestion process. A cycle of hypercongestion is made up of the initial additional journey time and then the average time afterwards at which the displaced travel is actually made. However, the elasticities of speed with respect to density are higher in the case of the Bangkok data and this increases the METC.

Again in Table 4.4.4, it is clear that the estimates of METC vary for different amounts of deterred demand adjustments. Again, a first best policy of correcting for congestion externality has to deal with the difficult problem of which estimates to use to set optimal externality Pigovian taxes and whether itr is appropriate to identify different types of road user, eg habitual and random.

The estimation of the marginal congestion external time costs are calculated using elasticities of speed with respect to density and speeds averaged over both outbound and inbound data. It is notable that average speeds in periods of hypercongestion are of the order of 20-40 km/h and 5-10 km/h for outbound and inbound routes respectively, see Figure 4..4.2. If these averages and the corresponding elasticities (see Table 4.4.3) are used to construct marginal external congestion costs, one finds the cost on the inbound route is in the order of 10 times larger than the outbound route. This is mainly the result of the much lower speeds on the inbound route. These results are not considered in detail but raise the policy difficulty of charging different Pigovian taxes for travel in opposite directions.

Table 4.4.4 Estimates of the Marginal External Time Congestion Costs for Chalerm Mahanakorn Expressway Bangkok

Hour	Type of Cong'n	Average speed km/h	$METC_{vsr}$ min/vkm	$METC_{sr}$ min/km	$METC_{lr}$ min/km
0.00	OC	80	0.08	0.08	0.07
1.00	OC	80	0.08	0.08	0.07
2.00	OC	80	0.08	0.08	0.07
3.00	OC	80	0.08	0.08	0.07
4.00	OC	80	0.08	0.08	0.07
5.00	OC	80	0.08	0.08	0.07
6.00	OC	60	0.12	0.12	0.11
7.00	OC	40	4.05	2.00	1.35
8.00	HC	20	37.26	5.17	2.78
9.00	HC	20	20.19	4.63	2.61
10.00	HC	20	9.64	2.85	1.67
11.00	OC	40	1.21	0.81	0.61
12.00	OC	60	0.11	0.11	0.10
13.00	OC	60	0.11	0.11	0.10
14.00	OC	60	0.11	0.11	0.10
15.00	OC	60	0.12	0.12	0.11
16.00	OC	40	0.17	0.16	0.15
17.00	OC	40	15.41	3.61	2.04
18.00	HC	10	103.86	10.76	5.68
19.00	HC	10	52.32	9.76	5.38
20.00	HC	10	26.59	4.14	2.24
21.00	OC	40	1.94	1.10	0.77
22.00	OC	55	0.11	0.10	0.10
23.00	OC	80	0.08	0.08	0.07

4.5 Conclusions

Following on from Chapter 3, a theory and model of the marginal external cost of hypercongestion is developed. This model clarifies the economic causes of hypercongestion and shows how the marginal hypercongestion externality can be estimated from data on only traffic speeds and flows.

The empirical analyses were carried out with two different data sets, i.e. Central London and the expressway in Bangkok.

Not surprisingly, the common characteristic of traffic in hypercongested streets in Central of London appears to be vertical speed-flow relations. This can be explained in terms of bottleneck congestion. It is suggested that the bottlenecks are caused by traffic lights that gave roughly constant flows. This implication of a vertical speed-flow relationship is that the elasticity of speed with respect to density is approximately one. This implies lower than otherwise METCs. Chapter 3 gives a full discussion of the METC for speed density in the region of one and gives estimates of the METC in hypercongestion is of the order one to two hours per vkm.

By contrast, the investigation of hypercongestion for the Chalerm Mahanakorn Expressway in Bangkok gives a traditional positive speed-flow relationship. The length of the hypercongestion periods are shorter and hypercongestion cycles are longer which both reduce the hypercongestion cost. However, the elasticity of speed with respect to density is higher and this effect increases the hypercongestion cost. The METC in hypercongestion periods is of the order of one hour per vkm.

The estimated METCs presented in this and Chapter 3 are indicative and have a large margin of potential numerical error. It is important to note that the estimates and theory considered in this Chapter take account of the congestion cost from longer duration of journeys but not of the costs of having to alter the timing of journeys.