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Summary:

Wintertime speed limits

An experimental study of speed limit effects

During the winters of 1997-98 and 1998-99, an experimental study on temporarily reduced wintertime speed limits was performed, involving a number of different two-lane road links in rural Norway. The aim has been to assess the effect of reduced wintertime speed limits on speed, under varying conditions. The possible impact on accident frequency or risk was beyond the scope of the study.

During the second winter season (December 1998 through April 1999), the speed limit was reduced, from 80 to 70 kms/h or from 90 to 80 kms/h, on a selected number of road links (the «treatment group»). The reduced wintertime speed limit remained in effect throughout the winter season, regardless of day-to-day variations in the weather or road surface conditions.

In addition, a «control group» was defined, consisting of road links on which no speed limit reduction was effected from the «before» period to the «after» period.

During both periods, traffic volumes and speed were recorded automatically by the hour, on the road links belonging to the treatment groups as well as within the control group.

In addition, officers from the local public roads administration would, at regular intervals (one to three times per day) during a certain period of time, record the current road surface and visibility conditions.

After pooling the data from all road links, we obtained a data set consisting of 32 224 units of observation, each unit being defined by an *hourly interval* at a given *road cross-section point* and a given *direction* of travel.

Road surface and visibility recordings were, however, available only for some of these units. Whenever the road surface and visibility conditions were identical between two points of observations, not more than 20 hours distant from each other, values were interpolated and included in the data set. In all other cases, the observation was discarded.

A certain number of observations were also discarded due to incomplete or obviously incorrect recordings on traffic volume and speed.

After purging the data set in this way, we were left with 16 786 units of observation, covering 18 different road links, each of them represented by two directions of travel.

Luminosity data (the amount of daylight and twilight prevailing at each point during each hourly interval) was added to each observation based on the point's geographic co-ordinates and an algorithm offered on the internet by the Astronomical Applications Department of the U S Naval Observatory.

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Methodology: Box-Cox regression

To analyze the data, the following statistical model was specified.

$$(1) \qquad f(y_{prt}) = a_p + b_p + \sum_i g_i g_i(x_{prti}) + \sum_j d_j d_{prtj} + \sum_{j,k} h_{jk} d_{prtj} d_{prtk} + u_{prt}\,.$$

Here, y_{prt} is the dependent variable (mean or 85th percentile speed) measured at road link *p* in direction *r* during (hourly) time interval *t*.

The parameters a_p are constant terms assigned to each road link, while the b_p parameters are constants representing «the opposite direction of travel» on each link. There are 18 a's and 18 b's in the model, meaning that we are, in fact, estimating a fully specified «fixed effect» panel data model, in which all cross-sectional differences between the 18 road links and between the two directions on each link are captured by the site specific constant terms. Only the temporal variations observable on the respective road links are exploited for purposes of estimating the substantive relationships of interest.

The variables x_{prti}, with coefficients g_i, are continuous independent variables measured on road link *p*, in direction r during time interval *t*, while the variables d_{prtj}, with coefficients d_j, are dummy variables capturing variations in speed limits, road surface conditions, visibility, etc.

The coefficients h_{jk} are interaction terms between, on the one hand, road surface and visibility dummies and, on the other hand, the speed limit dummies. By specifying a full set of (first order) interaction terms one can, in principle, estimate a separate speed limit effect for each road surface and visibility condition.

The last term u_{prt} is a random disturbance term with (by assumption) zero expected value, zero correlation across observations, and a variance which is inversely proportional to the number of vehicles passing point *p* in direction r during interval *t*.

The functions $f(\ )$ and $g(\ )$ are monotonous transformations, whose curvature we do not specify *a priori*, but *estimate* simultaneously with the coefficients $a_p, b_p, g_i, d_j,$ and h_{jk}. This is achieved by means of *Box-Cox-transformations*, given by

$$(2) \qquad f(y) = y^{(l)} \equiv \begin{cases} \dfrac{y^l - 1}{l} & \text{if } \ l \neq 0 \quad (y > 0) \\ ln(y) & \text{if } \ l = 0. \end{cases}$$

The parameter l is the *Box-Cox-parameter*. It defines the shape of the curve as linear ($l = 1$), quadratic ($l = 2$), cubic ($l = 3$), the square root ($l = 0.5$), logarithmic ($l = 0$), hyperbolic ($l = -1$), or *anything in between* these shapes, since l need not be an integer. Interestingly, the Box-Cox-transformation is continuous at $l = 0$, because

(3) $$\lim_{l \to 0}\left(\frac{y^l - 1}{l}\right) = ln(y).$$

The Box-Cox-transformation applied to the *dependent* variable has the special effect of determining whether the *independent* variables affect the dependent variables in a *linearly additive* manner or in some way implying, e g, decreasing marginal returns. If $l > 1$, there are decreasing returns to increments in the independent variables, so that the cumulative effect of two independent variables changing is smaller than the sum of the two individual effects – in a manner of speaking, «the effect of the sum is smaller than the sum of the effects». If, on the other hand, $l < 1$, the opposite is true, all independent variables strengthening the effect of each other. In the special case $l = 0$, the relationship would be essentially multiplicative.

The Box-Cox regression model is estimated by means of the BC-GAUHESEQ (Box-Cox Generalized AUtoregressive HEteroskedastic Single Equation estimation) algorithm of the TRIO software package, developed by Gaudry et (1993) (see also Liem et al 1993).

Empirical results

Curvature of relationship

While the linearly additive model has the advantage of being easily interpretable and understandable, the non-additive model turns out to provide a clearly superior fit, at least as applied to the *mean speed* variable. Here, the dependent variable Box-Cox-parameter is estimated at 2.027, translating into an almost exactly quadratic transformation on the left-hand side variable, or – equivalently – a square root transformation as applied to the entire right-hand side predictor.

For the 85th percentile speed (dependent) variable, a close to linearly additive relationship is estimated, the left-hand side Box-Cox parameter being estimated at 1.130.

Note, however, that in both of these cases, separate Box-Cox transformations are also applied to various *independent* variable (*viz*, to the *traffic volume*, to the *share of heavy vehicle traffic*, and to the *interaction terms* between the *initial*, site specific *speed level* and the wintertime *speed limit* dummies).

Thus, even if the left-hand side Box-Cox parameter in the equation explaining the 85th percentile speed is close to one, the relationship between this speed level indicator and, say, the traffic volume, is not necessarily close to linear.

Speed and traffic flow

Indeed, the estimated partial relationship between speed and traffic volume is shown in Figure 1.

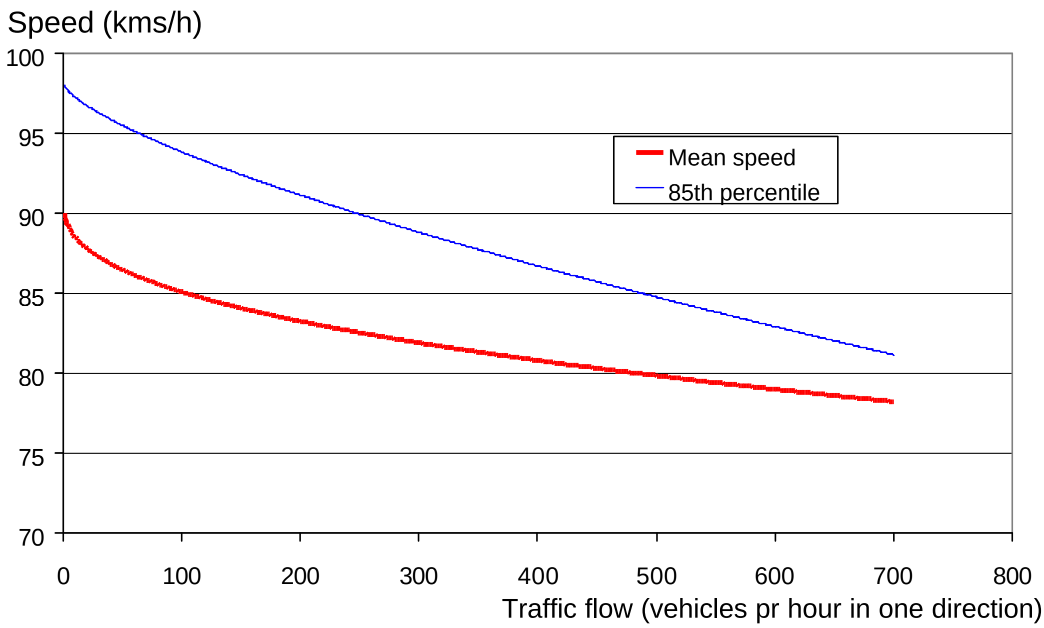

Figure 1: Estimated partial relationship between speed and traffic flow.

The maximum traffic flow observed in our data set is 700 vehicles per hour in one direction. The normal capacity per lane is of the order of 1 500 to 2 000 vehicles per hour. Thus, our data set hardly includes any observations pertaining to heavily congested situations.

Yet, one notes a clearly decreasing speed-volume relationship level starting already at very modest traffic density levels.

Speed limits and road surface conditions

In Figure 2, we show the estimated partial relationships between reduced wintertime speed limits and speed, under varying road surface conditions and varying initial («before» period) speed levels. The diagram applies to road links with an ordinary speed limit of 80 kms/h (the most current limit on rural roads in Norway), which – as part of the experiment – had their speed limit lowered to 70 during the «after» period.

One notes that the speed limit is most effective (in terms of reducing speed) on those road links which exhibit high levels of speed prior to the speed limit reduction. The relationship between the speed reduction and the prior speed level is, however, markedly non-linear, as revealed by our Box-Cox regression model.

Also, one notes that the speed reduction effect of the wintertime speed limit is largest when the road surface conditions are *not* those typical of wintertime driving. This is shown more clearly in Figure 3.

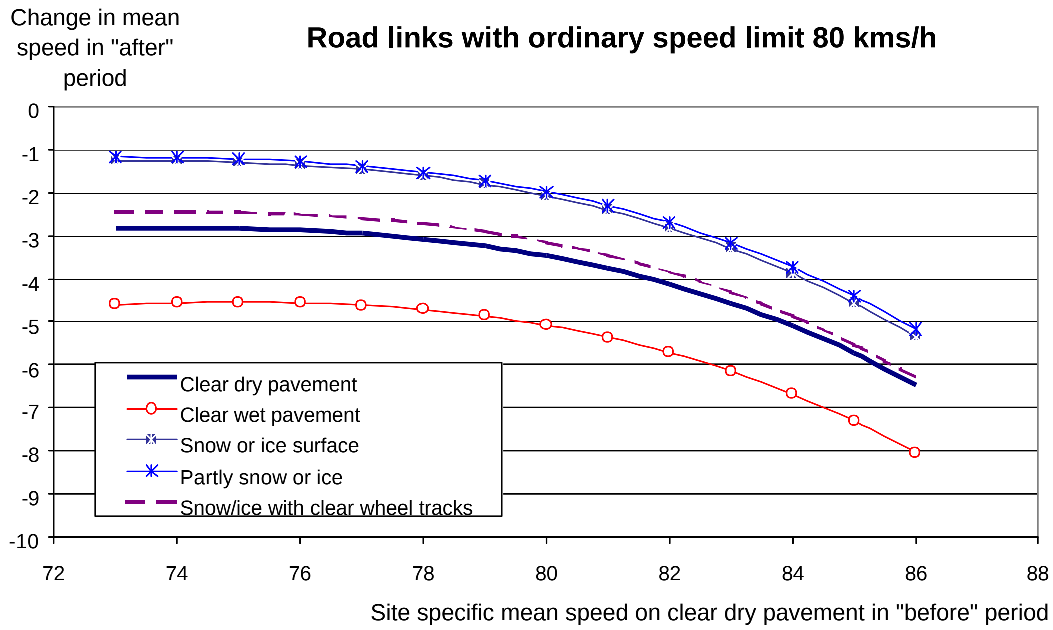

Figure 2: Estimated partial relationship between ***mean speed*** *and* ***wintertime speed limit reduction from 80 to 70 kms/h****, contingent on initial speed level and on current road surface conditions.*

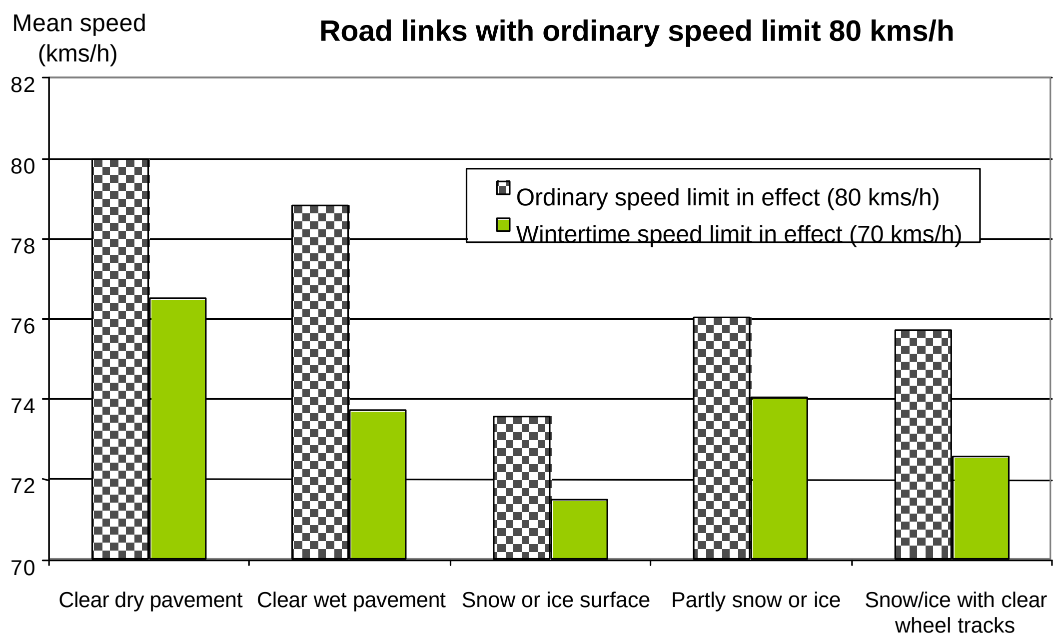

Figure 3: Estimated partial relationship between ***mean speed, wintertime speed limit reduction from 80 to 70 kms/h****, and* ***road surface conditions****. Numerical example for a road with prior mean speed on clear dry pavement equal to the speed limit.*

On a road link with a 80 kms/h speed limit, motorists typically reduce their speed by an estimated 6.5 kms/h when the surface is covered by snow or ice. An *additional* 2 kms/h reduction is obtained when a 10 kms/h speed limit reduction is effectuated, bringing the mean speed reduction to 8.5 kms/h, as compared to the situation with a clear dry pavement and an 80 kms/h limit.

On a clear *dry* pavement, however, the isolated (partial) effect of a 70 kms/h speed limit is an estimated 3.5 kms/h. On a clear *wet* asphalt surface, a full 5 kms/h speed reduction due to the lowered speed limit can be expected.

Thus, there is evidence that motorists voluntarily adjust their speed in response to a more slippery road surface, as would be expected under the «risk compensation» («behavioral adjustment») hypothesis.

Visibility and luminosity

Our regression model shows very modest and partly insignificant effects of changes in visibility and luminosity.

Indeed, variations in the amount of daylight, as measured (inversely) by the prevalence of twilight or night-time darkness during the hour of observation, affect the mean speed by less than 1 km/h. A slightly lower speed is observable during the night, when the traffic volume and other independent variables are controlled for.

The difference between «good visibility» and «poor visibility» (fog etc), as recorded by the officers of the local public roads administration, is also relatively small: 1-2 kms/h reduced mean speed under poor visibility.

Unlike the result found for risky road surface conditions, the *interaction* between wintertime speed limits and poor visibility is such as to *strengthen* somewhat the speed reducing effect of a reduced speed limit.

Conclusion

Lowered wintertime speed limits in Norway have been shown to have a significant, independent speed reducing effect.

Paradoxically, the independent effect of the wintertime speed limit is smaller under typical winter conditions than on a clear pavement. This is so because motorists voluntarily adjust their behavior in response to increasing extraneous risk.

The speed reducing effect of a lowered wintertime speed limit increases convexly with the site specific speed level prior to the speed limit reduction.