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Association between increase in fixed penalties and road safety outcomes: a meta-analysis

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ABSTRACT

Studies that have evaluated the association between increases in traffic fine amounts (fixed penalties) and changes in compliance with road traffic law or the number of accidents are synthesised by means of meta-analysis. The studies were few and different in many respects. Nine studies were included in the meta-analysis of changes in compliance. Four studies were included in the meta-analysis of changes in accidents. Increasing traffic fines was found to be associated with small changes in the rate of violations. The changes were non-linear. For increases up to about 100 percent, violations were reduced. For larger increases, no reduction in violations was found. A small reduction in fatal accidents was associated with increased fixed penalties, varying between studies from less than 1 percent to 12 percent. The main pattern of changes in violations was similar in the fixed-effects and random-effects models of meta-analysis, meta-regression and when simple (non-weighted) mean values were computed. The main findings are thus robust, although most of the primary studies did not control very well for potentially confounding factors. Summary estimates of changes in violations or accidents should be treated as provisional and do not necessarily reflect causal relationships.

Key words: traffic tickets, violations, accidents, road traffic law, evaluation studies, meta-analysis

1 INTRODUCTION

Many motorised countries have a system of fixed penalties for common traffic offences. A fixed penalty is a fixed amount of money to be paid when a road user pleads guilty to committing a certain offence. Fixed penalties are commonly applied for speeding offences, non-use of seat belts, and other common traffic offences. Fixed penalties tend not to be continuously adjusted in line with consumer prices, but are increased steeply every few years. As an example, the Australian state of Queensland increased fixed penalties for speeding on April 17, 2003 (Watson et al. 2015). For minor violations (less than 15 km/h above the speed limit), there was a modest increase from 90 to 100 Australian dollars. For the most serious violations (speeding by more than 40 km/h), the fixed penalty increased from 255 to 700 Australian dollars.

Are increases in fixed penalties associated with a reduction in the number of traffic offences and accidents? A number of studies have been made to answer this question (Nilsson and Åberg 1986, Andersson 1989, Fridstrøm 1999, Poli de Figueiredo et al. 2001, Elvik and Christensen 2007, Wagenaar et al. 2007, Cedersund 2008, Maffei de Andrade et al. 2008, Tavares et al. 2008, Montag 2014, Moolenaar 2014, Sebego et al. 2014, Bhalla et al. 2015, Elvik 2015, Watson et al. 2015, Killias et al. 2016). The findings are, however, not entirely consistent, and no formal synthesis of the evidence provided by these studies has been found. The objective of this paper is to summarise current knowledge regarding the association between changes (mostly increases) in fixed penalties (the term traffic fines is used synonymously) and changes in road user compliance with road traffic laws and changes in the number of accidents. Before reviewing relevant studies, theoretical perspectives on the relationship between traffic fines and road user compliance with the law will be discussed.

2 THEORETICAL PERSPECTIVES AND RESEARCH QUESTIONS

Economic theory offers two perspectives on the effects of increasing traffic fines on road user compliance with road traffic laws. According to the standard economic model of crime, proposed by Becker (1968) in a seminal paper, offenders weigh the costs and benefits of violations. An increase in fixed penalties increases the expected cost of committing a violation and is therefore expected to deter violations.

A game-theoretic model of crime and enforcement, on the other hand (Tsebelis 1989, 1990, 1993; Bjørnskau and Elvik 1992), predicts that increasing fixed penalties has no effect on the rate of violations, because the police adapt to increased penalties by reducing enforcement, thus keeping the expected value of the cost of crime (cost = risk of detection · size of penalty) constant.

One study (Elvik and Christensen 2007) found no support for the game-theoretic model. Another study (Elvik 2015) found some, albeit statistically very weak, support for the game-theoretic model. Thus, the empirical studies have produced inconsistent findings as to which of the theoretical models is best supported by data.

Two stated preference studies (Hössinger and Berger 2012, Ryeng 2012) shed light on how drivers say they adapt to changes in fixed penalties. According to Hössinger and Berger (2012) drivers stated that doubling the fixed penalty would be associated with a reduction in speeding of about 10 percent. Ryeng (2012), on the other hand, did not find that increasing fixed penalties would influence speeding. Hence, the two stated preference studies also produced inconsistent findings.

Based on the theoretical perspectives and the results of previous studies, the main questions the research synthesis presented in this paper seeks to answer are:

1. Is an increase in fixed penalties associated with a reduction in the rate of traffic violations?
2. Is there a dose-response relationship between the size of the increase in fixed penalties and the size of the reduction in the rate of traffic violations?
3. Is an increase in fixed penalties associated with a reduction in the number of accidents?

3 STUDY RETRIEVAL AND CODING

Studies were identified by searching Sciencedirect and the Ovid Transport Database. The following search terms were used: "traffic tickets", "fixed penalties" and "fines". In addition, studies quoted in the Handbook of Road Safety Measures (Høye et al 2015) were examined. Table 1 list the studies that were found. There are two groups of studies: (1) Studies that use some indicator of road user compliance with road traffic law as the dependent variable, and (2) Studies that use changes in the number of accidents as dependent variable. The majority of studies use an indicator of compliance as dependent variable.

Table 1 about here

Two meta-analyses were made. The first meta-analysis included nine studies of changes in compliance. Only one study (Nilsson and Åberg 1986) was omitted because it did not state results in sufficient detail. The second meta-analysis included four studies of changes in the number of accidents. Two studies reporting such changes were omitted from the meta-analysis. One of these studies (Poli de Figueiredo et al. 2001) relied on data for only one year before and one year after the change. A subsequent study (Maffei de Andrade et al. 2008) found these years to be atypical of long-term trends. That study included a longer period, but did not state the number of accidents precisely enough to be included (results were presented in diagrams not stating the exact number of accidents). Table 1 states for each study whether it was included in the meta-analysis or not. The following information was coded for each study:

1. Publication year
2. Country
3. Level of violations
4. Potential moderator variables
5. Percentage change in fixed penalties
6. Study design
7. Estimator of effect
8. Confounders controlled for

Table 2 shows the coding of these variables for each study. Publication year was included in order to assess whether study findings change over time. Country was included to assess the similarity of findings between countries. Fixed penalties normally vary according of the severity of a violation. Level of violation was therefore included.

Table 2 about here

A moderator variable is any variable that influences the size of an effect. The most important moderator variable with respect to increases in traffic fines is the risk of apprehension. The change in fixed penalties is stated as a percentage in order to evaluate whether there is a dose-response relationship between changes in fixed penalties and changes in the rate of violations. All changes except one were increases. The exception (Bhalla et al. 2015) was the abolition (i.e. 100 percent reduction) of the fixed penalty for speeding by 10-20 km/h in Russia in 2013. Study design was included in order to assess whether different study designs produce different results. The estimator of change in compliance is in most cases changes in the percent of cars speeding. This is stated as a ratio, e. g. if 45 percent were speeding before an increase in fixed penalties and 42 percent after the increase, the change is stated as 42/45 = 0.933. Finally, a list of confounding factors controlled for was made for each study.

4 EXTRACTION OF ESTIMATES OF EFFECT AND THEIR STANDARD ERRORS

4.1 Changes in compliance

The studies stated estimates of changes in compliance in different metrics and did not always include estimates of the standard errors. To permit a meta-analysis, all estimates must be stated in the same metric and all standard errors must be known. In general, the statistical weight assigned to an estimate in meta-analysis is:

$$\text{Fixed-effects statistical weight} = \frac{1}{SE_i^2}$$

SE_i is the standard error of the i-th estimate.

The oldest study, Andersson (1989), stated the percentage of cars speeding in four cities in Sweden before and after an increase in fixed penalties. The number of cars included in the data set was estimated by relying on Table 5 in the report. A distinction was made between speeding by less than 10 km/h and speeding by 10 km/h or more. A total of eight estimates were extracted from the study (four cities · two levels of speeding).

The standard error associated with a single data point was estimated as follows:

$$\text{Standard error} = \sqrt{\frac{(Proportion\ speeding) \cdot (1 - proportion\ speeding)}{Number\ of\ cars\ measured}} \qquad (1)$$

Thus, for the city of Nässjö in the before period, 24.6 percent were speeding by less than 10 km/h. 8,594 cars were included in the speed data. The standard error for this data point therefore becomes:

$$\text{Standard error} = \sqrt{\frac{(0.246) \cdot (1 - 0.246)}{8594}} = 0.00464575$$

The standard error of the data point referring to the after period was estimated as 0.00477777. The rate of speeding in the after period in the city of Nässjö was 26.8 percent. The estimator of effect was therefore:

Estimate $(\widehat{R})$ = 26.8/24.6 = 1.089.

The reasons for stating effects as ratios is that they are then comparable to accident modification factors, and that they are dimensionless. Moreover, they lend themselves to meta-analysis by means of the logodds inverse variance technique, which is by far the most common method of meta-analysis in the field of road safety. The standard error of the estimate of effect was estimated as follows:

$$\text{Standard error of estimate of effect} = \widehat{R} \cdot \sqrt{SE_{before}^2 + SE_{after}^2} \qquad (2)$$

This estimator is only an approximation. Strictly speaking, the standard error of a rate depends on the covariance between its numerator and denominator, not just on the standard error of the numerator and the standard error of the denominator. However, as the covariance is unknown and the data needed to estimate it is not available, the simple approximation in equation 2 will be used.

The method explained above was used to extract estimates of effect and their standard errors in the studies of Andersson (1989), Watson et al. (2015) and Killias et al. (2016).

Fridstrøm (1999) stated the results of analysis in terms of model coefficients and the T-values associated with these coefficients. Based on these coefficients, he extracted model estimates of changes in seat belt use and the standard errors of these changes. A note explaining the procedure in detail (Fridstrøm 2016) is available on request.

Elvik and Christensen (2007) presented results in terms of percentage changes in violation rates and 95 % confidence intervals for these changes. For example, speeding at camera sites was reduced by 1.4 percentage points according to the logistic model (corresponds to a reduction in violation rate at camera sites from 15.0 % to 13.6 %, which implies an estimate of effect = 0.907). The 95 % confidence interval spanned from 0.5 percentage points of increase in speeding (15.5/15.0 =

1.033) to 3.1 percentage points of reduction in speeding (11.9/15.0 = 0.793). An estimate of the standard error was obtained from the confidence interval as follows:

$$\text{Standard error} = \frac{(\ln(1.033) - \ln(0.793))}{3.92} = 0.06745$$

The same method was applied to the study reported by Bhalla et al. (2015).

Cedersund (2008) stated effects as differences in the estimated percentage speeding before and after the increase in fixed penalties. The estimates were based on a least squares linear regression model. As an example, the percentage speeding near a speed camera (any level of speeding) was estimated as 28.08 % before and 23.46 % after the increase of fixed penalties. The 95 % confidence interval associated with this difference spanned 19.45 percentage points (from a reduction of 14.35 % to an increase of 5.10 %, implying that the estimated reduction from 28.08 to 23.46 % was not statistically significant at the 5 % level). The standard error associated with the reduction in speeding was estimated as 19.45/3.92 = 4.96 percentage points. Thus, the difference in speeding was 28.08 – 23.46 = 4.62 percentage points with a standard error of 4.96 percentage points. The value of the standard error exceeds the value of the estimate of effect by a factor of 4.96/4.62 = 1.074. The estimate of effect was converted to a ratio: 23.46/28.08 = 0.835 (a reduction of 0.165). The standard error of this estimate was then approximated as: 0.165 · 1.074 = 0.177. Again, the procedure is clearly not ideal from a statistical point of view, but it is an approximation based on the data available.

Moolenaar (2014) estimated elasticities. These were converted to estimates of effect by multiplying them with the percent increase in fixed penalties during the period covered by the study (2007-2010). This increase was estimated to be 24.8 %. At speed camera sites, this implies an estimate of 24.8 · –0.139 = –3.4 or 3.4 percent accident reduction (an accident modification factor of 0.966). The standard error of the estimated elasticity (–0.139) obtained from the T-value was 0.0767. The standard error of the estimate of effect was estimated as (0.0767/0.139) · 0.034 = 0.018. A similar procedure was applied to the study of Elvik (2015).

While the procedures used to extract estimates of effect and their standard errors are not ideal, they preserve the statistical significance of the findings, i.e. findings that were statistically significant before conversion remain so after conversion. The same applies to findings that were not statistically significant. A total of 43 estimates were extracted from the studies. Estimates were found to have a large between-study variation and the main analysis relied on a random-effects model. In the random-effects model, the statistical weight assigned to each estimate is:

$$\text{Random-effects statistical weight} = \frac{1}{SE_i^2 + \tau^2}$$

The variance component, τ^2 is fixed and therefore leads to a considerable flattening of the statistical weights.

4.2 Changes in accidents

Estimates of changes in the number of accidents were also stated as ratios. Estimates based on Wagenaar et al. (2007) were extracted from Table 4 of the study. As an example, the change in fatal accidents with a blood alcohol concentration (BAC) between 0.01 and 0.07 percent in Arizona was estimated as –18.2 percent. Stated as a ratio, this is 0.818. The corresponding reduction in the number of fatalities was estimated to be –0.41, with a standard error of 0.63. The standard error exceeds the estimate by 0.63/0.41= 1.536. Applying this multiplicator to the percentage change yields a standard error of 28 percent, or 0.28 when stated in the same ratio metric as the estimated change.

The changes in the number of accidents estimated by Tavares et al. (2008) were extracted from Table 2 of the study. The standard errors in this study were particularly small, meaning that it was assigned a considerably larger statistical weight than any of the other studies dealing with changes in the number of accidents. Estimates from Montag (2014) were based on Table 3, model 6 in his paper. Coefficients were converted to accident modification factors (ratios) by taking the exponential function of the coefficients. Standard errors were used as stated in the paper. Finally, Sebego et al. (2014) stated both accident modification factors and their confidence intervals, from which standard errors were obtained. A total of 67 estimates were extracted; 57 of these came from Wagenaar et al. (2007).

5 EXPLORATORY ANALYSIS

5.1 Changes in violations

Before performing a meta-analysis, one should do an exploratory analysis to determine if it makes sense to proceed to a full analysis. A useful tool for performing exploratory analysis is the funnel plot. Figure 1 shows a funnel plot of the 43 estimates of changes in violation rate. The scales were defined as recommended by Sterne and Egger (2001).

Figure 1 about here

Ideally speaking, the distribution of data points in a funnel plot should be symmetric and have the shape of a funnel turned upside down. Data points with large standard errors should display a greater dispersion than data points with small standard errors. The data points in Figure 1 do not show such a pattern. There is a clustering of data points near the top of the diagram. All these data points have small standard errors, but still show considerable variation. A funnel plot looking like Figure 1 would normally suggest that a meta-analysis makes little sense because of the wide dispersion of the data points.

However, despite the somewhat uncommon distribution of data points in the funnel plot, the dispersion of estimates of effect is not exceptionally large. 23 of the 43 estimates are contained within the range from plus 15 % to minus 15 %. A further 6 data points indicate a reduction of violations of between 15 and 30 %. It is not uncommon in meta-analyses of road safety evaluation studies to see a considerably larger spread of estimates of effect than this. As an example, estimates of effect in a meta-analysis of studded tyres (Elvik 1999) ranged between –70 % and +10 % (all road surface conditions).

Nevertheless, the fact that the data points at the top of the funnel plot are as widely spread as they are suggests that the main focus of a meta-analysis must be on identifying sources of this variation. When testing for the presence of outlying data points, 15 data points were found to be outlying according to the fixed-effects model. This is an artefact of the very small confidence interval of the summary estimate of effect in the fixed-effects model. According to the random-effects model, no data point was classified as outlying. The main analysis is therefore based on the random-effects model.

The trim-and-fill technique (Duval and Tweedie 2000A, 2000B, Duval 2005) was applied to test for publication bias, i.e. the tendency not to publish results that are regarded as uninteresting or difficult to interpret. According to the fixed-effects model, the analysis indicated publication bias, suggesting the deletion of most estimates showing a reduction in the rate of violations (see Figure 1). Again, this is not very plausible and is probably an artefact of the small standard errors associated with most data points, including the data points showing an increase in the rate of violations.

5.2 Changes in accidents

A funnel plot of estimates of the changes in accidents associated with changes in fixed penalties was prepared as part of the exploratory analysis. Figure 2 shows the funnel plot.

Figure 2 about here

The study of Tavares et al. (2008) dominated completely and made up 99.6 percent of the statistical weights because of its small standard errors. Nevertheless, the funnel plot has a somewhat more normal appearance than the funnel plot shown in Figure 1. A trim-and-fill analysis indicated publication bias; however due to the large weight of the study by Tavares et al. (2008) this did not influence the summary estimate. It is difficult to combine the studies statistically, since a single study contributes almost all the statistical weight. The studies of changes in accidents will therefore be presented separately in the results section of the paper.

6 RESULTS

6.1 Changes in compliance

The main analysis was performed in two stages. First, a subgroup analysis was performed in order to assess the presence of a dose-response relationship between changes in fixed penalties and changes in the rate of violations. The results are reported in Table 3.

Table 3 about here

The results are inconsistent. While both a simple mean and the random-effects summary estimate indicate a weak (statistically non-significant) tendency for violations to go down, the fixed-effects summary estimate indicates an increase in violation rate of about 7 percent. Considering the very large heterogeneity of estimates, the random-effects analysis is regarded as the most informative. The random-effects analysis indicates that increasing fixed penalties by between 50 and 100 percent is associated with a reduction of the rate of violations. However, it appears that when fixed penalties increase by more than 100 percent, there is no further reduction of violations. On the contrary, a tendency for violations to increase is seen. Figure 3 shows a plot of all 43 data points serving as the basis for the summary estimates in Table 3.

Figure 3 about here

A second degree polynomial has been fitted to the data pointes in Figure 3. However, as shown by the R-squared statistic, the polynomial fits the data points quite poorly. In the second stage of analysis, meta-regression analysis was run in order to test whether the relationship shown in Figure 3 held up in a multivariate analysis. The following variables were defined for the meta-regression:

1. Year (entered as a numerical variable 1989, …, 2015)
2. Dummy for Sweden
3. Dummy for Norway
4. Dummy for Switzerland
5. Dummy for other countries
6. Percent change in fixed penalties
7. Percent change in fixed penalties squared (preserving the negative sign for the abolition of fixed penalties for speeding by 10-20 km/h in Russia)

The meta-regressions were run using an SPSS macro (Lipsey and Wilson 2001). Due to software constraints, the model could not be run including all independent variables. Three models were run. All included year, increase in fixed penalties, increase in fixed penalties squared and one country dummy. The results are presented in Figure 4. The curves were fitted to models including one of the countries listed at the bottom. The thick curve is the mean of three models.

Figure 4 about here

Figure 4 confirms that the relationship between increase in fixed penalties and reduction in the rate of violations is non-linear and has a turning point. Possible reasons for this pattern will be discussed in the discussion section of the paper.

6.2 Changes in accidents

Results of the four studies that have evaluated changes in the number of accidents associated with changes in fixed penalties are listed in the lower panel of Table 3. As noted before, the studies did not lend themselves very well to meta-analysis because the study reported by Tavares et al. (2008) totally dominated the statistical weights. Hence, any summary estimate would reflect the contribution from that study only.

The results of the four studies are consistent in that all of them indicate a small decline in the number of accidents. All the estimates listed in Table 3 refer to fatal accidents or to the number of fatalities.

The changes in fixed penalties studied by Wagenaar et al. (2007) ranged from a reduction of 100 dollars to an increase of 1,000 dollars. Was there any relationship between the size of the change in fixed penalties and the size of the change in the number of fatalities in alcohol-related accidents? Figure 5 sheds light on this question.

Figure 5 about here

Figure 5 shows that a second degree polynomial best fits the data points. When fixed penalties are increased, the number of fatalities is reduced up to a certain point. Beyond that point, further increases in fixed penalties are not associated with larger reductions in the number of fatalities. It is intriguing that the pattern shown in Figure 5 is very similar to the patterns shown in Figures 3 and 4 with respect to changes in violation rate.

7 DISCUSSION

There are almost always two ways to interpret the findings of research: methodological and substantive. A methodological interpretation will often argue for rejecting findings as only showing poor data or poorly designed studies that are prone to error and bias. A substantive explanation, on the other hand, will often propose a causal interpretation of study findings.

With respect to the research presented in this paper, methodological problems can arise at two levels: the level of primary studies and the level of meta-analysis. As far as the meta-analysis is concerned, the following problems are worth mentioning:

1. The analysis of changes in compliance included only 9 studies with a total of 43 estimates of effect. 36 of these estimates originated in three countries: Norway, Sweden and Switzerland.
2. Meta-analysis of studies of changes in accidents was impossible, as one of the studies totally dominated the statistical weights.
3. Multiple estimates of effect in the same study can be statistically dependent.
4. It was difficult to obtain statistically correct estimates of the standard error associated with each estimate of changes in violation rate in the primary studies.

A meta-regression analysis was performed to statistically test and control for differences between countries with respect to estimates of changes in compliance associated with changes in fixed penalties. The analysis found that the relationship between changes in fixed penalties and changes in the rate of violations was not very much affected by potential confounding from country of origin or the year in which a study was made.

Statistical dependence between multiple results of the same study cannot be ruled out. In the study that produced the largest number of estimates of changes in compliance, Killias et al. (2016), the data came from five different cities and referred to three levels of violations. The dispersion of estimates of changes in the rate of violations was not smaller in this study than in the other studies; if anything, it was larger, see Figure 6.

Figure 6 about here

The large variation in the estimates produced by Killias et al. (2016) is not consistent with the idea that statistical dependence reduces the variation between estimates. This suggests that statistical dependency between estimates in a single study may not be a problem.

It was difficult to correctly estimate the standard error of each estimate of effect. Simplifications had to be adopted, but these do not seem to have influenced the results of analysis very much. Four analyses were performed: (1) A simple mean of individual estimates (not weighted); (2) A fixed-effects meta-analysis; (3) A random-effects meta-analysis; (4) A meta-regression. The main pattern in the findings was highly consistent in these four analyses. This indicates that the main findings of the study are unlikely to be biased as a result of the problems encountered in the meta-analysis.

As far as the primary studies are concerned, they were, as is normally the case, of different quality. The most important aspect of study quality in road safety evaluation studies is control for potentially confounding factors. Not all studies controlled for the same potentially confounding factors. It has been argued (Rossi 1987) that: "The better designed the impact assessment of a social program, the more likely is the resulting estimate of net impact to be zero." (The Stainless Steel Law of Evaluation). In the present context, this means that studies controlling for comparatively many confounding factors will find smaller effects than studies controlling for comparatively few confounding factors.

It is difficult to see such a pattern in the studies included in this analysis. Andersson (1989), for example, did not control for many confounding variables; yet the mean value of his estimates of effect was close to zero. Moolenaar (2014) and Elvik (2015) both found a reduction of violations in studies that controlled for many confounding variables. On the whole, however, the quality of primary studies in terms of controlling for confounding variables falls short of what one would require of studies to support a causal interpretation of their findings. These studies show statistical associations that may or may not be causal.

An intriguing pattern that was found both in the studies of changes in compliance and in one of the studies of changes in the number of accidents was that increasing fixed penalties was associated with a reduction of violations or accidents only up to a certain point. Beyond that point, the changes became smaller, in particular for violation rate. As mentioned in the literature review, it has been suggested that the police adapt to major increases in fixed penalties by reducing enforcement. The empirical evidence for this is, however, virtually absent, with only one study (Elvik 2015) weakly indicating that such an effect might exist. Indirectly, the findings of this study support the hypothesis that the police may respond to large increases in fixed penalties by reducing enforcement. It should be noted, however, that this is not the only possible interpretation of the patterns that were found. The offences that are targeted by large increases in fixed penalties tend to be committed less frequently than less serious offences, and are thus more difficult to focus on in enforcement. Moreover, one can imagine that drivers who commit the most serious offences are less deterred by fixed penalties than drivers who do not commit these offences.

8 CONCLUSIONS

The main conclusions of the research presented in this paper can be summarised as follows:

1. Changes in fixed penalties for traffic law violations are, on the average, associated with small changes in the rate of violations.
2. There is a dose-response relationship between the size of the increase in fixed penalties and the size of the reduction in violations. This relationship has a turning point for very large increases in fixed penalties.
3. Study findings were found to vary over time and between countries, but the relationship between changes in fixed penalties and changes in the rate of violations remained after confounding by time and country were statistically controlled for in a meta-regression analysis.
4. Increases in fixed penalties are associated with a small reduction of the number of accidents, in the order of around 5-10 percent.
5. Most primary studies did not control sufficiently well for potentially confounding factors to justify a causal interpretation of the findings of the meta-analysis.

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LIST OF FIGURES AND TABLES

Table 2:

Characteristics of studies included in meta-analysis

Table 3:

Results of meta-analysis

Table 1:

Studies (chronologically)	Country	Dependent variable	Inclusion in meta-analyses
Nilsson and Åberg 1986	Sweden	Rate of speeding	Not included; too imprecise information about dependent variable
Andersson 1989	Sweden	Rate of speeding	Included in meta-analysis using compliance as dependent variable
Fridstrøm 1999	Norway	Rate of seat belt wearing	Included in meta-analysis using compliance as dependent variable
Poli de Figueiredo et al. 2001	Brazil	Number of accidents	Not included; short-term data inconsistent with long-term trends
Elvik and Christensen 2007	Norway	Rate of speeding; rate of seat belt wearing	Included in meta-analysis using compliance as dependent variable
Wagenaar et al. 2007	United States	Number of accidents	Included in meta-analysis using accidents as dependent variable
Cedersund 2008	Sweden	Rate of speeding	Included in meta-analysis using compliance as dependent variable
Maffei de Andrade et al. 2008	Brazil	Number of accidents	Not included; too imprecise data about the number of accidents
Tavares et al. 2008	Portugal	Number of accidents	Included in meta-analysis using accidents as dependent variable
Montag 2014	Czech Republic	Number of accidents	Included in meta-analysis using accidents as dependent variable
Moolenaar 2014	Netherlands	Tickets issued	Included in meta-analysis using compliance as dependent variable
Sevego et al. 2014	Botswana	Number of accidents	Included in meta-analysis using accidents as dependent variable
Bhalla et al. 2015	Russia	Rate of speeding	Included in meta-analysis using compliance as dependent variable
Elvik 2015	Norway	Rate of speeding	Included in meta-analysis using compliance as dependent variable
Luca 2015	United States	Number of accidents	Not included; deals with amount of enforcement
Watson et al. 2015	Australia	Rate of speeding	Included in meta-analysis using compliance as dependent variable
Killias et al. 2016	Switzerland	Rate of speeding	Included in meta-analysis using compliance as dependent variable

Table 2:

Study	Year	Country	Levels of violations	Moderator variables	Percentage change in fixed penalties	Study design	Estimator of effect	Confounders controlled for
Panel A: Studies included in meta-analysis using compliance as dependent variable								
Andersson	1989	Sweden	Two: <10 kmh; >10 kmh	None	+ 50% for <10 kmh; + 33% for >10 kmh	Before-and-after	Change in percent of cars speeding	Level of enforcement (conventional)
Fridstrøm	1999	Norway	One (seat belt worn or not)	Rural or urban	+ 67%	Multivariate logit model	Change in percent of drivers wearing seat belts	Percent of cars with seat belts installed; law making use mandatory; publicity campaigns
Elvik, Christensen	2007	Norway	One (seat belt worn or not; car speeding or not)	Rural or urban; speed camera	+ 29% for speeding + 50% for seat belts	Multivariate log-linear models	Changes in percent of cars speeding and percent of drivers wearing seat belts	Year; location
Cedersund	2008	Sweden	Three: <10 kmh; >10 kmh; >20 kmh	Speed camera	+ 93%	Least-squares linear regression	Change in percent of cars speeding	Location; time of day
Moolenaar	2014	Netherlands	One (car speeding or not)	Speed camera	+ 25% (2007-2010)	Multivariate log-linear models	Number of fines issued	Unemployment; GDP; annual trend; season; heavy vehicle; vehicle-related speed limit; location
Bhalla et al.	2015	Russia	Two: 10-20 kmh; 20-40 kmh	None	10-20: -100%; 20-40: + 67%	Least-squares linear regression	Change in percent of cars speeding	Month; season; year
Elvik	2015	Norway	One (car speeding or not)	None	+ 24%	Multivariate log-linear models	Change in percent of cars speeding	Year; rural dummy; violation level; citation rate; fuel price; level of enforcement
Watson et al.	2015	Australia	Three: <15 kmh; 15-29 kmh; 30- kmh	None	+ 11% for <15 kmh + 48% for 15-29 kmh + 130% for 30- kmh	Before-and-after	Change in percent of drivers speeding	Confounding by changes in enforcement are discussed

Table 2:

Study	Year	Country	Levels of violations	Moderator variables	Percentage change in fixed penalties	Study design	Estimator of effect	Confounders controlled for
Panel A: Studies included in meta-analysis using compliance as dependent variable								
Killias et al.	2016	Switzerland	Three < 5 kmh; 6-10 kmh; 10- kmh	City	+100% for <5 kmh +200% for 6-10 kmh +317% for 10- kmh	Before-and-after	Change in percent of cars speeding	Confounding by changes in enforcement are discussed
Panel B: Studies included in meta-analysis using accidents as dependent variable								
Wagenaar et al.	2007	United States	Three: BAC 0.1-0.7; 0.8-1.4; 1.5-	State	In most cases from 0 to a positive amount	ARIMA time-series analysis	Percent change in number of accidents	Month; changes in jail sentences
Tavares et al.	2008	Portugal	Not specified	None	Stated as a dummy only	ARIMA time-series analysis	Percent change in number of accidents	Month; vehicle inspections, precipitation
Montag	2014	Czech Republic	Not specified	Time	+ 200% for speeding	Negative binomial regression	Percent change in number of fatalities	GDP per capita; freight transport; cars per capita; mean age of cars
Sebego et al.	2014	Botswana	Not specified	Time	About 100 % (stated as intervals only)	Time-series analysis and Poisson regression	Percent change in fatal and non-fatal accidents	Month; seasonal variation

Table 3:

	Model used to estimate summary estimate of effect		
Group of studies	**Simple mean (not weighted)**	**Fixed-effects**	**Random-effects**
	Panel A: Changes in violation rate (e.g. 0.90 =10% reduction)		
All studies (N=43)	0.998 (0.890; 1.106)	1.069 (1.067; 1.071)	0.958 (0.863; 1.064)
	Different sizes of changes in fixed penalties		
Abolishing penalty (100% reduction) (N=1)	1.465 (1.388; 1.546)	1.465 (1.388; 1.546)	1.465 (1.388; 1.546)
Increase of up to 50% (N=17)	0.968 (0.898; 1.038)	0.996 (0.993; 0.999)	1.000 (0.962; 1.039)
Increase between 50 and 100% (N=14)	0.891 (0.703; 1.079)	0.997 (0.989; 1.004)	0.851 (0.714; 1.014)
Increase of more than 100% (N=11)	1.139 (0.823; 1.455)	1.143 (1.140; 1.146)	1.040 (0.788; 1.372)
	Panel B: Changes in the number of accidents (0.90 = 10 % reduction)		
Wagenaar et al. 2007	0.962 (0.932; 0.994)		
Tavares et al. 2008	0.996 (0.993; 0.998)		
Montag 2014	0.884 (0.773; 1.010)		
Sebego et al. 2014	0.880 (0.818; 0.947)		

Figure 1:

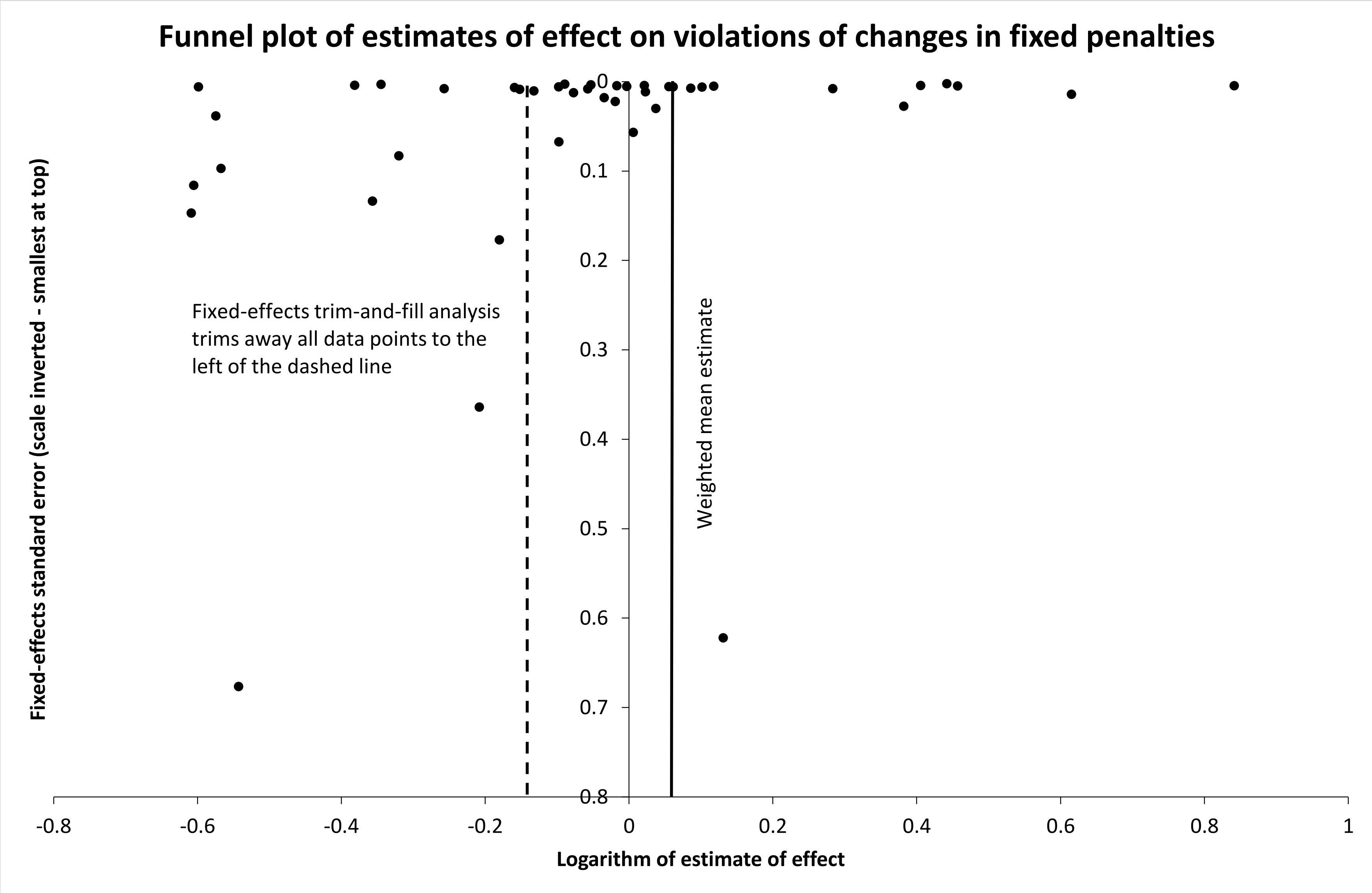
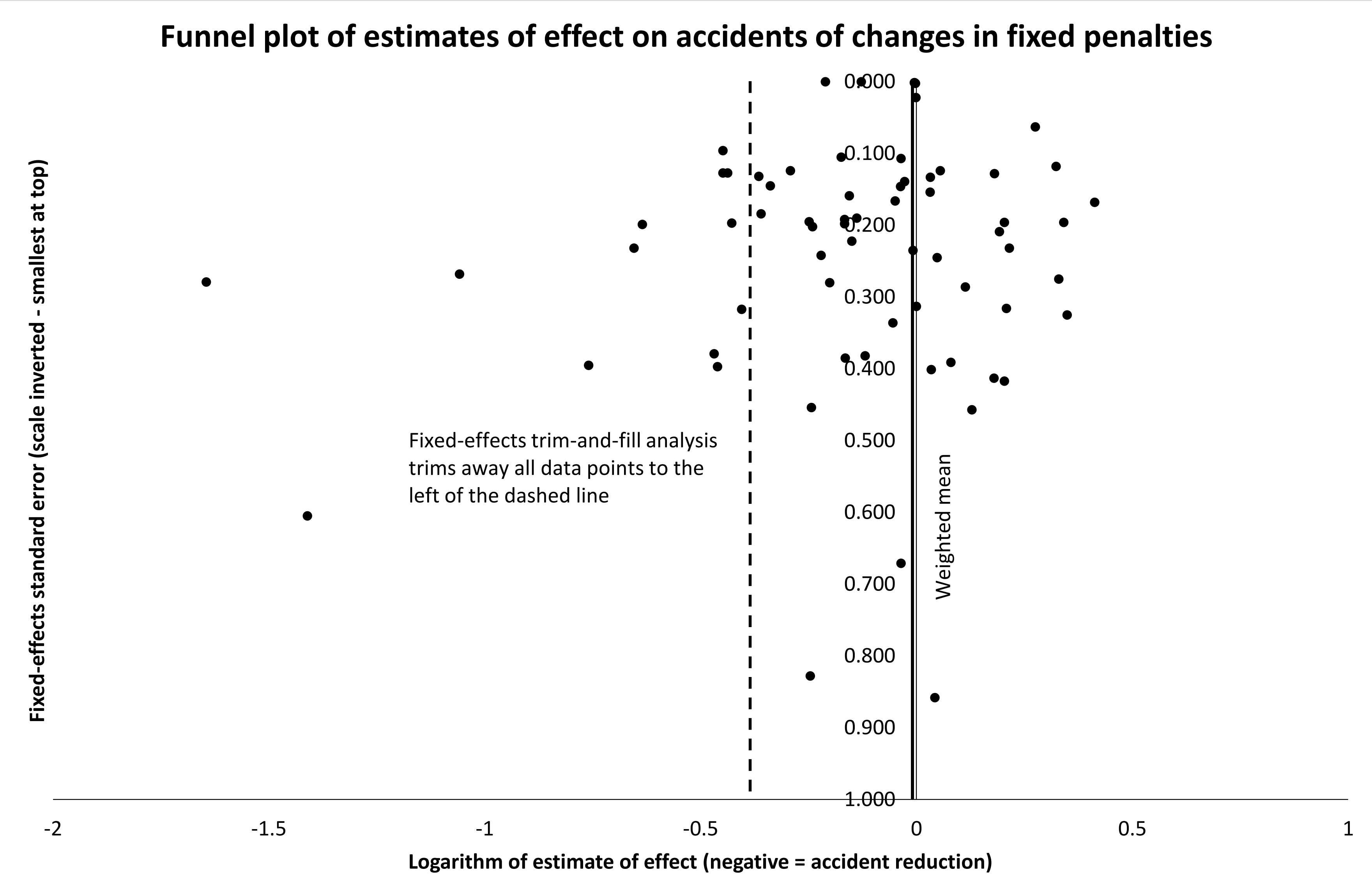

Funnel plot of estimates of effect on violations of changes in fixed penalties
Fixed-effects standard error (scale inverted - smallest at top)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Fixed-effects trim-and-fill analysis trims away all data points to the left of the dashed line
Weighted mean estimate
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
Logarithm of estimate of effect

Figure 2:



Funnel plot of estimates of effect on accidents of changes in fixed penalties
Fixed-effects standard error (scale inverted - smallest at top)
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
0.800
0.900
1.000
Fixed-effects trim-and-fill analysis trims away all data points to the left of the dashed line
Weighted mean
-2
-1.5
-1
-0.5
0
0.5
1
Logarithm of estimate of effect (negative = accident reduction)

Figure 3:

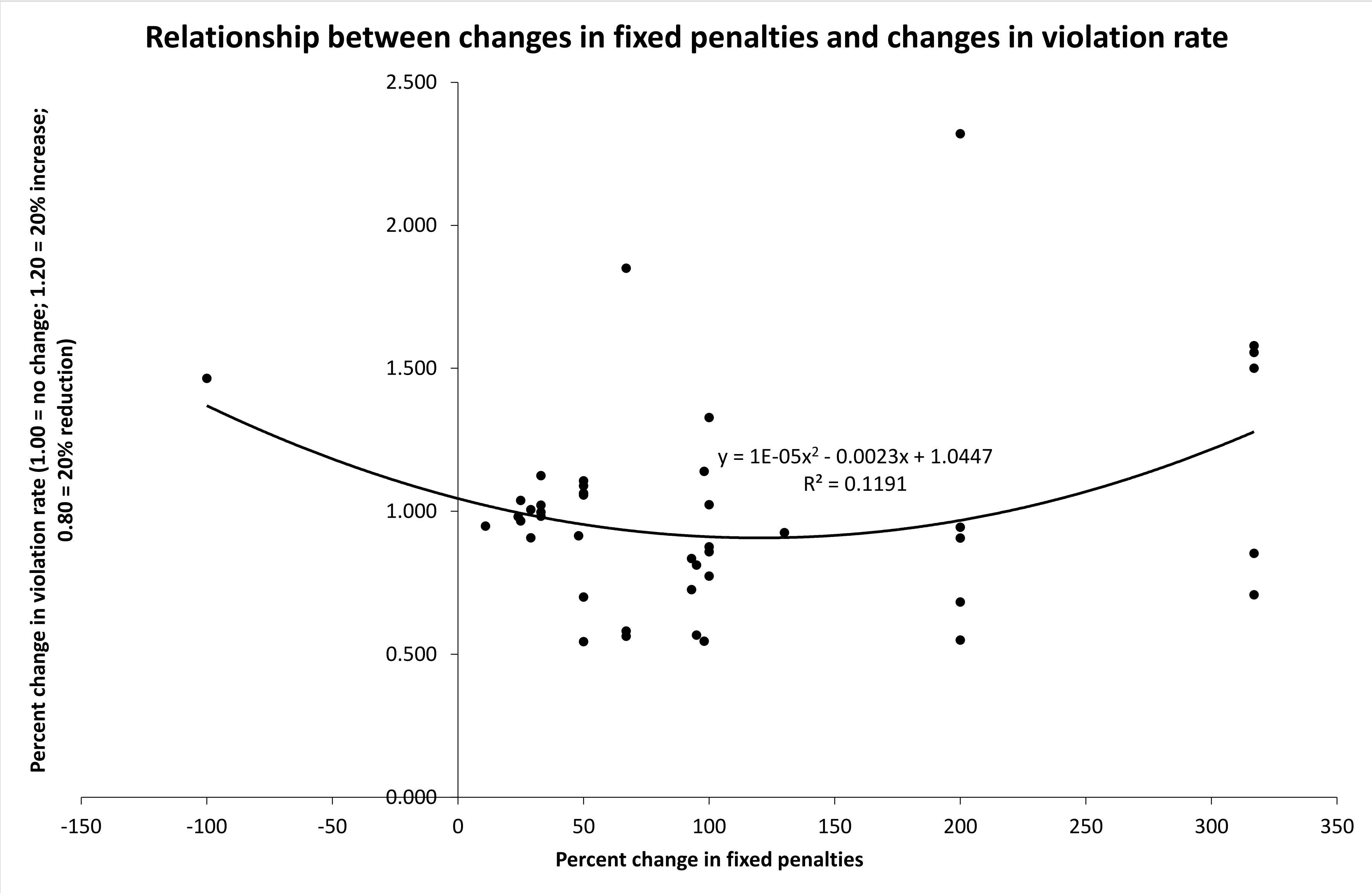
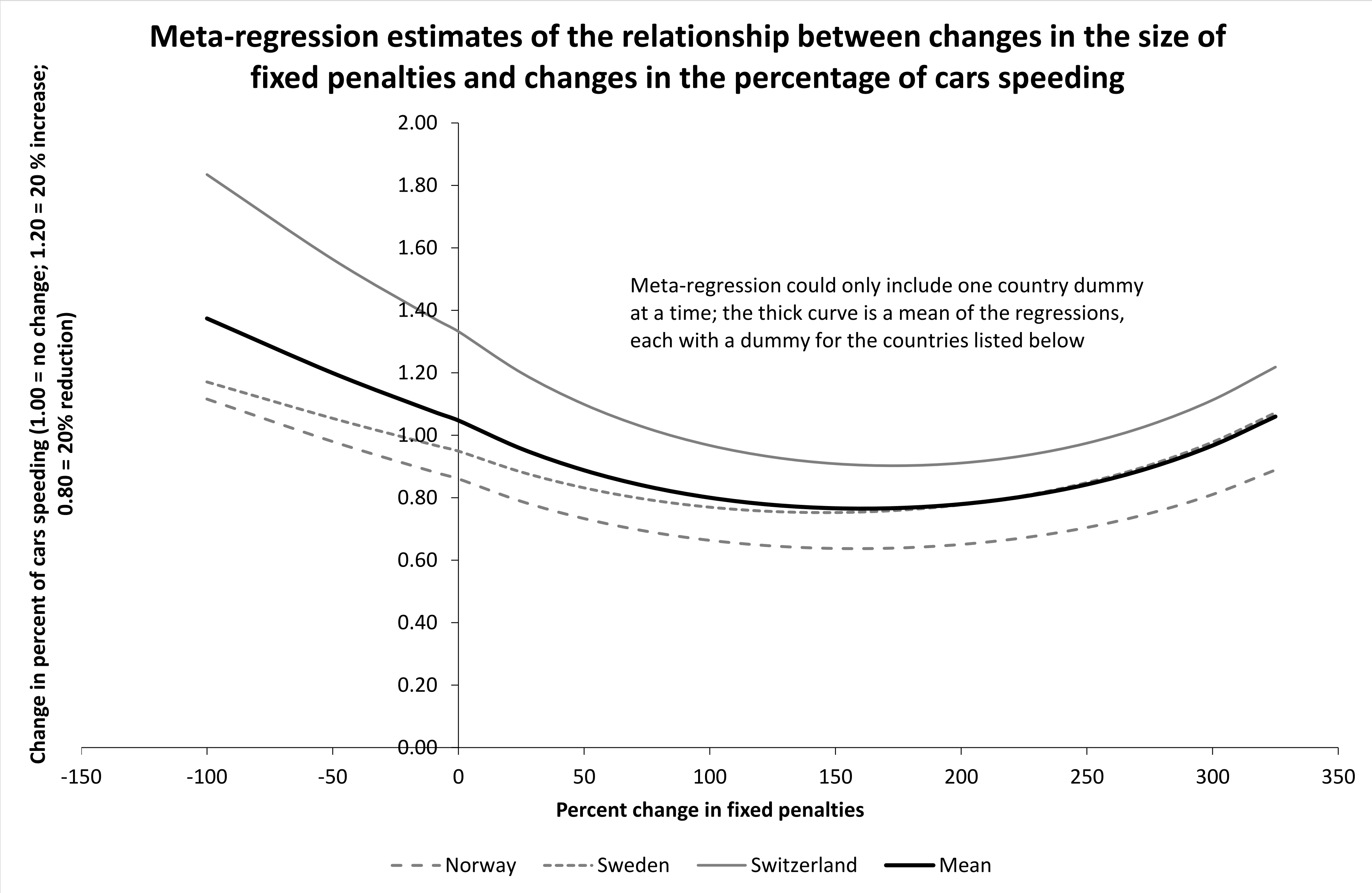
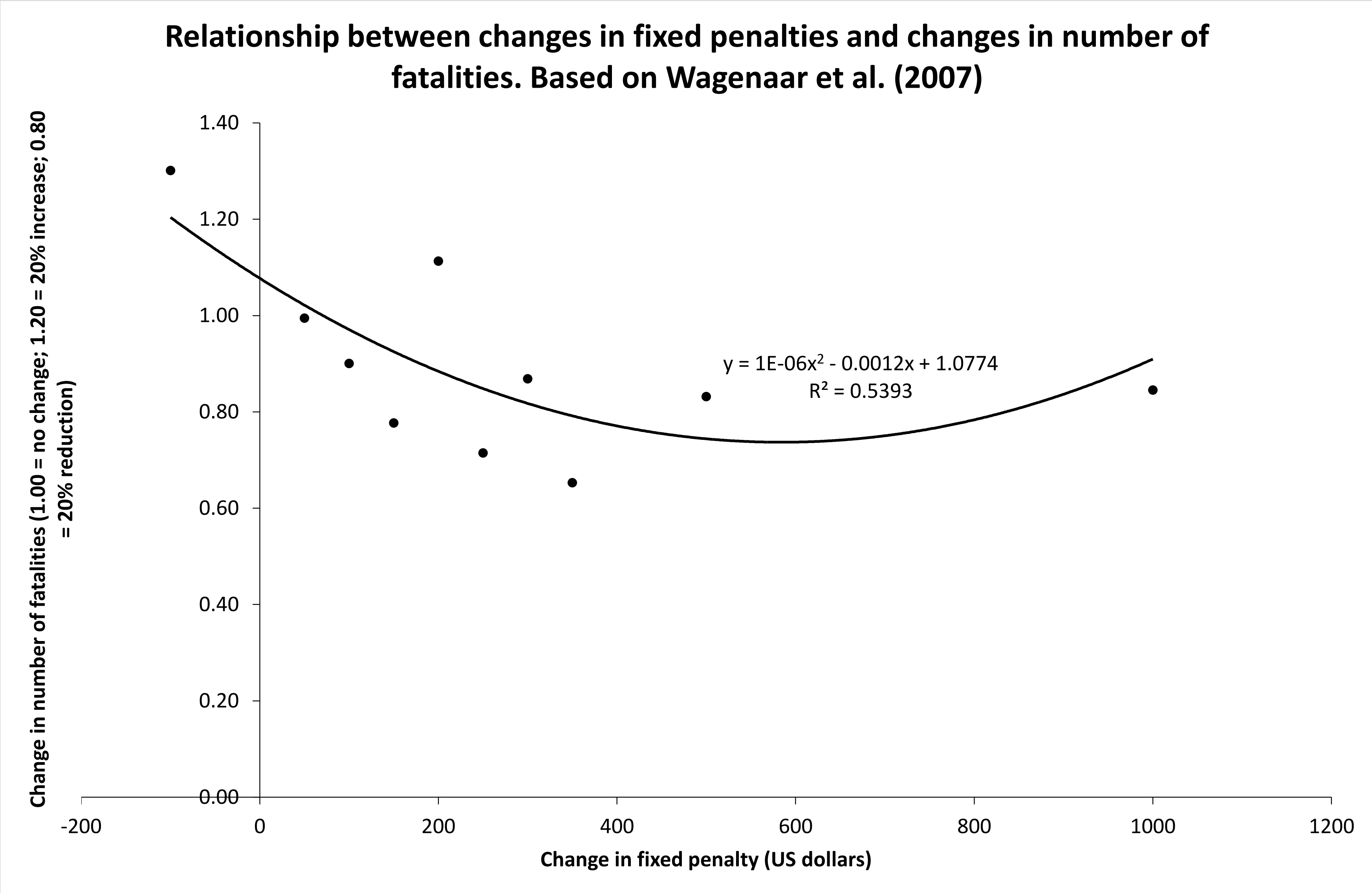

Relationship between changes in fixed penalties and changes in violation rate
Percent change in violation rate (1.00 = no change; 1.20 = 20% increase; 0.80 = 20% reduction)
2.500
2.000
1.500
1.000
0.500
0.000
y = 1E-05x² - 0.0023x + 1.0447
R² = 0.1191
-150
-100
-50
0
50
100
150
200
250
300
350
Percent change in fixed penalties

Figure 4:



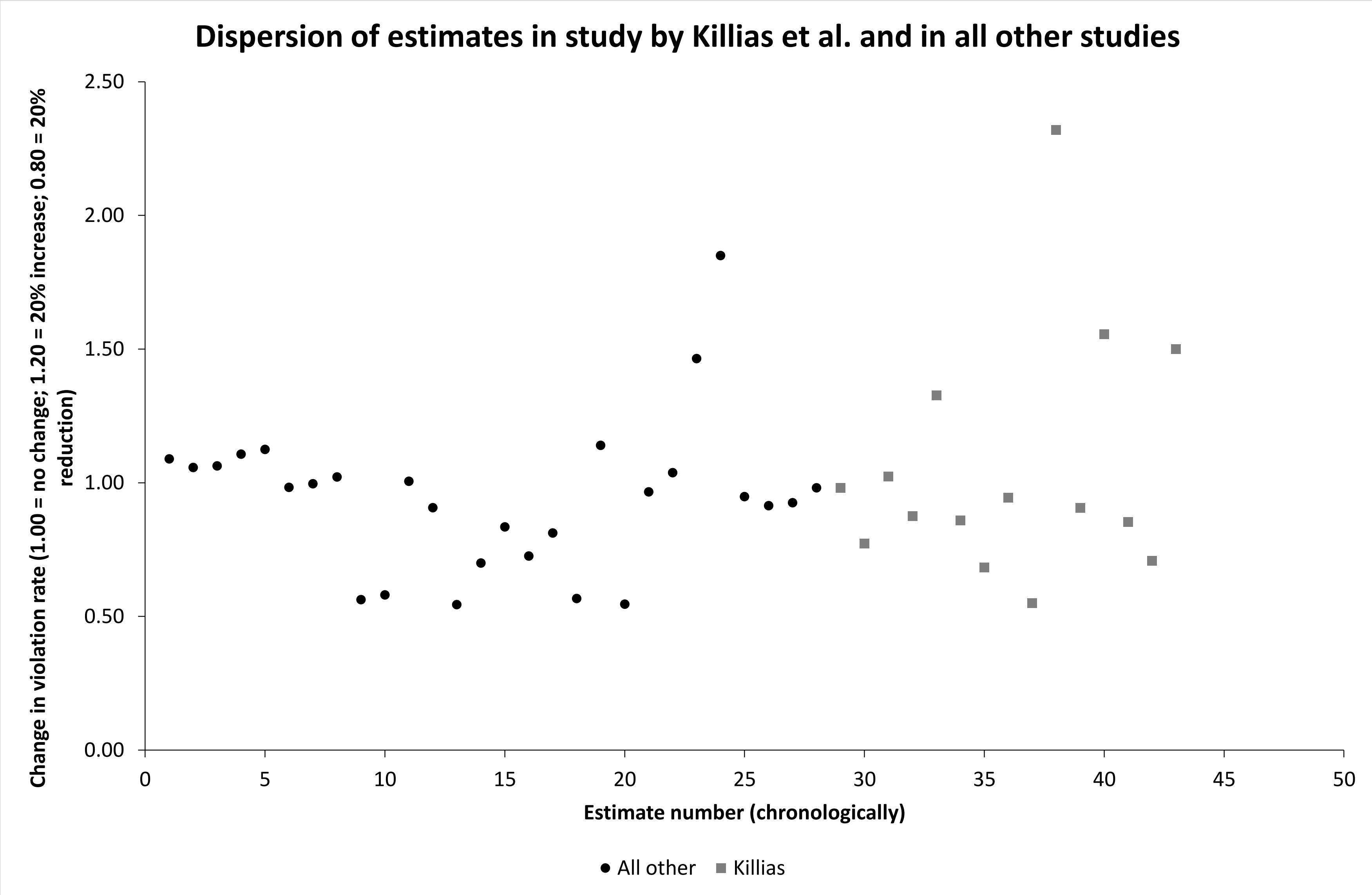
Meta-regression estimates of the relationship between changes in the size of fixed penalties and changes in the percentage of cars speeding
Meta-regression could only include one country dummy at a time; the thick curve is a mean of the regressions, each with a dummy for the countries listed below
Change in percent of cars speeding (1.00 = no change; 1.20 = 20 % increase; 0.80 = 20% reduction)
Percent change in fixed penalties
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-150
-100
-50
0
50
100
150
200
250
300
350
Norway
Sweden
Switzerland
Mean

Figure 5:



Relationship between changes in fixed penalties and changes in number of fatalities. Based on Wagenaar et al. (2007)
Change in number of fatalities (1.00 = no change; 1.20 = 20% increase; 0.80 = 20% reduction)
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-200
0
200
400
600
800
1000
1200
Change in fixed penalty (US dollars)
y = 1E-06x² - 0.0012x + 1.0774
R² = 0.5393

Figure 6:



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