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ANALYSING THE IMPACTS OF COMBINED ENVIRONMENTAL EFFECTS - CAN STRUCTURAL EQUATION MODELS (SEM) BE OF BENEFIT?

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ABSTRACT
Regression models for estimating exposure-effect relationships are not necessarily the best choices when the purpose is to estimate regression coefficients for ascertaining the effect of noise changes on noise annoyance. Multivariate regression models assume that the independent variables are measured without errors while both exposure and effect variables are measured with error. It is well known that measurement errors in the simplest cases lead to an attenuation of the regression coefficients and an underestimation of the effect of noise exposure changes. Regression models not taking into account a broader range of environmental indicators also suffer from the "omitted variable" problem resulting in erroneous parameter estimates. We provide some simple examples of how SEM can be of help and provide a platform for building more comprehensive models.

1 - INTRODUCTION
Exposure-effect curves established from community surveys describe the relationship between noise exposure found at people's apartment and noise reaction measures such as the degree of annoyance. Such exposure-effect curves can be used for predicting the annoyance in similar communities given the noise exposure. Using the size of the estimated regression coefficients to predict the effect of noise reduction and abatement measures on annoyance is however questionable. This paper provides some examples and benefits of Structural Equation Models (SEM) that take into account measurement errors and problems of omitted variables. SEM can also take into account the modeling of interactions, nonlinearities, correlated independents and correlated error terms. SEM may be used as a more powerful alternative to multiple regression, path analysis, factor analysis, time series analysis, and analysis of covariance. In practice, much SEM-research combines confirmatory and exploratory purposes: a model is tested using SEM procedures, possibly found to be deficient, and an alternative model is then tested based on changes suggested by SEM modification indexes. Theory- and/or data-driven modelling strategies are always a source of debate! We use data from the Oslo Traffic study to illustrate the use of SEM, rather than present new results. Results from single equation logic models were presented at the 1998 Internoise and ICBEN conferences [1, 2].

2 - OSLO TRAFFIC STUDIES
The Oslo Traffic Studies consist of three environmental studies that were undertaken in the autumns of 1987, 1994 and 1996. They function as before and after studies of two separate stages in the construction of a new main road with two tunnel projects alleviating an East Oslo city-area of through traffic. The study area is composed of eight sub-areas with uniform building types of mostly brick houses 2 to 4 stories high. In addition to being one of the areas carrying most traffic the quality of life in the study area is among the lowest in Norway. The noise reaction measures used in the surveys are the degree of annoyance with road traffic noise when indoors, and when right outside their apartment. Air pollution reaction measures are responses to survey questions on the degree of annoyance with exhaust/odour and dust/grime respectively when right outside the apartment. All annoyance scales are categorical with values: 1=does not hear/notice, 2=not annoyed, 3=a little annoyed, 5=highly annoyed (category

4 somewhat annoyed is lacking in these studies). Noise calculations are of 24 h equivalent continuous sound pressure levels $L_{\text{pAeq,24h}}$ at the apartment's most exposed side. The Nordic calculation method includes 3 dB from facade reflection. The neighbourhood maximum is an indicator for a neighbourhood with much traffic noise. It is defined as the largest respondent $L_{\text{pAeq,24h}}$ value within 75 m radius of each respondent. As general air pollution indicator the 3-month mean value ($\mu g/m^3$) of nitrogen dioxide (NO_2) at the most exposed facade was used. Air pollution calculations were performed with a combined line and area model on the basis of meteorological data and traffic flows for each hour [3]. The surveys are described more fully in [4]. Structural equation models that are used as examples are based on the pooled data sets from sub-areas experiencing traffic reductions. Non response was about 50 %. Records missing data were deleted listwise, leaving approximately 1800 respondents.

3 - EXAMPLE 1: THE EFFECT OF MEASUREMENT ERROR

Regression models do not take measurement errors into account. As both exposure and reaction measures are measured with error, the estimated relationship between the noise exposure and the noise reaction is attenuated [5] − the regression coefficients describing the effect of noise reductions (increases) are too small. In our first example we use a simple exposure-effect model to demonstrate the effect. The dependent variable is a single noise reaction measure, the annoyance with road traffic noise when right outside ones apartment (**Outdoors**). The independent variables are the calculated $L_{\text{pAeq,24h}}$ at the apartment, (**LEQ**), indicators of low (**SENS1**) and high (**SENS2**) noise sensitivity. Two indicators (**1994**) and (**1996**) separate the surveys in 1994 and 1996 from the 1987 survey before the traffic reductions.
In figure 1 we have explicated the transformation of a multivariate linear regression model − left panel, to SEM models were two of the terms, noise exposure (**Noise**) and Annoyance with road traffic noise (**Ann noise**) are treated as latent variables equipped with simple measurement models − middle and right panel.

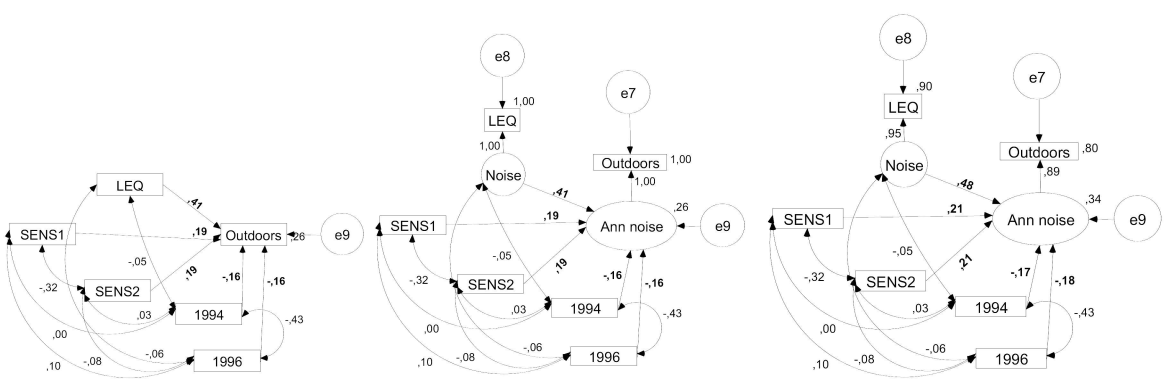

Figure 1: Left: regression model; middle: equivalent SEM with variance of e7 and e8 fixed to zero; right: same SEM with à priori fixed measurement error; standardised coefficients.

Observed variables are in the Path diagrams described by rectangular boxes. Error terms are described by circles. Latent variables are described as ovals. The estimated standardised regression coefficients are printed along the paths (directed arrows →). Correlation coefficients are printed along the curved bi-directional arrows ↔.
The measurement models are given by the linkage of road traffic noise exposure to the single indicator **LEQ** and road traffic noise annoyance to the single indicator **outdoors** respectively. The standard errors **e7** and **e8** of the SEM in the middle are fixed to zero forcing the latent noise exposure and noise reaction variables to be identical to their respective indicators. These variables are thereby the same as in the multivariate regression model on the left. For the model in the right panel of Figure 1, we distinguish between the variables we wish to establish a relationship between, and their indicators. The variance of **e8** is fixed=4. This means that each $L_{\text{pAeq,24h}}$ -value is assumed to be measured with a standard error of 2 dBA. The variance of the error term **e7** for outdoor noise annoyance is fixed at 0,4. This gives a standard error of approximately 0,6 scale points. The size of the measurement errors should be fixed from knowledge of the quality of data and previous research. Assessment of measurement quality is also dependent of how one conceptualises noise exposure and noise annoyance [6].
The SEM differs slightly from the regression model in the left panel of figure 1 in the assumption that noise sensitivity dummies are uncorrelated with noise exposure. This assumption provides an opportunity to test the model − that the covariance matrix implied by the model system is consistent with the sample

covariance matrix. Usually indexes revealing different aspects of fit are examined first. If the model does not fit the data, there is little sense in trying to interpret the path coefficients. Estimation of the models using AMOS 4.0 from Smallwaters/SPSS resulted in acceptable fit indexes (GFI=1, RMSEA=0, Hoelter0,05=9808). We have tried to guard a little against the violation of normality assumptions implicit in using ordinal level data by using both Generalised Least Squares estimation and Maximum Likelihood estimation. Both estimation methods gave the same results.
After assuring acceptable fit the next step is to examine the path coefficients. The estimated SEM in the middle of figure 1 with no measurement errors explains 26 % of the variance in noise annoyance (multiple correlation coefficients are printed above and to the right of dependent variables =0,26) same as for the linear regression model. When measurement error is taken into account see figure 1 − right panel, the path coefficient along the path from noise exposure ($L_{\mathrm{pAeq,24h}}$) to noise annoyance increases from 0,41 to 0,48. The amount of explained variance in noise annoyance increases from 26 % to 34 %. Assuming that the measurement errors were fixed appropriately, this means an upward adjustment of the estimated effect of road traffic noise exposure on road traffic noise annoyance by 17 %.

4 - EXAMPLE 2: OMITTED NEIGHBOURHOOD NOISE INDICATOR

Exposure-effect relationships estimated from community studies are different from relationships established in the laboratory. In the laboratory noise exposure can be manipulated directly keeping other factors constant. In the field, noise exposures are unavoidably associated with other environmental and population group factors. Where ground conditions are soft, vibration from landbased transport is clearly such a factor. Road traffic noise exposure in the neighbourhood can also contribute to noise annoyance at the apartment [7]. As apartments being exposed to the same $L_{\mathrm{pAeq,24h}}$-values can have quite different noise neighbourhoods, failure to take into account neighbourhood noise represents an "omitted variable" problem. SEM can be used for assessing the consequences of such an omitted variable by comparing the Path diagrams from models with and without an indicator of the maximum road traffic $L_{\mathrm{pAeq,24h}}$-values for respondents in the neighbourhood (**Neigh Max**). For people living in quiet side streets, this neigbourhood maximum can be high, while apartments facing main streets in some cases will have neighbours only exposed to similar or lower noise levels.
To simplify the following examples we assume that both $L_{\mathrm{pAeq,24h}}$ values at the residence and in the neighbourhood are measured without error. The SEM-model without and with an indicator for noise exposure in the neighbourhood is depicted in figure 2.

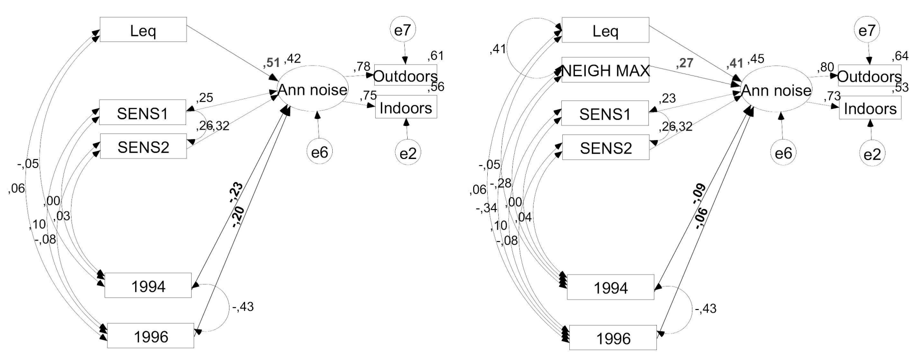

Figure 2: SEM without neighbourhood noise indicator − left panel; SEM with neighbourhood noise indicator − right panel; standardised coefficients.

The first issue after estimating the models is whether the model shows acceptable fit to the sample covariance matrix. In the given example the model can be said to show acceptable fit (GFI=0,996, RMSEA=0,038, Hoelter0,05=996). Inspecting the path coefficients next: Neighbourhood noise seems to play an important part in explaining noise annoyance. The Path coefficient is 0,27 or about 2/3 of the effect of the noise level at the apartment on noise annoyance (0,41). The Path coefficient for the path linking noise at the apartment to noise annoyance has on the other hand been reduced from 0,51 to 0,41. This implies that noise abatement efforts only affecting noise levels at apartments, and not the neighbourhood are not generally so effective as the SEM in the left panel of figure 2 would lead one to believe. Noise abatement efforts reducing noise exposure both at the apartment and in the neighbourhood can on the other hand produce an enhanced effect. To test that the coefficient for the effect of the neighborhood traffic noise is significantly different from zero, the fit of models with and

without the parameter fixed to zero are compared. Such a test show that fixing the path from the neighbourhood noise indicator to noise annoyance to zero is not consistent with the data.
Reductions in noise annoyance after traffic flow reductions that are unaccounted for by the actual changes in $L_{\mathrm{pAeq,24h}}$-values, is well known in the noise research litterature [8]. Such an "overreaction" to noise reductions is represented in the left panel of figure 2 by the two non-zero path coefficients from the survey year dummy variables (**1994** and **1996**) to road traffic noise annoyance. However, the reductions in neighbourhood maximum $L_{\mathrm{pAeq,24h}}$ from 1987 to 1994/1996 are also much larger than the reduction of the $L_{\mathrm{pAeq,24h}}$-values at people's apartment – see figure 3 – left panel. The SEM in the right panel of figure 2 taking into account relative changes in neighbourhood noise levels, results in path coeffisients from the year dummies to road traffic noise annoyance that are nearly zero. Thus in this study the "overreactions to noise reductions" appears to be nothing but the indirect effect of an omitted exposure variable. In the Oslo Studies both air pollution and residential road traffic levels were also shown to change relatively more in sub-areas where traffic was reduced than the $L_{\mathrm{pAeq,24h}}$ values at people's apartment changed. We have coined the term "Area-effect" to describe these effects of traffic flow changes to a town-area [2]. The large relative changes in the Neighbourhood Max values can be seen as part of such an effect. There is however still the problem of discriminating between the effects of neighbourhood noise and air pollution changes for road traffic noise annoyance changes.

5 - EXAMPLE 3: MULTI EQUATION MODEL WITH AIR POLLUTION

Several researchers [9-13] have indicated that the relationship between road traffic noise and noise annoyance is modified by additional environmental exposures – in particular air pollution and traffic insecurity. Typically people exposed to high noise levels are also exposed to high levels of other environmental hazards. The correlations between air pollution and noise indicators were in the order of 0,50 in the Oslo studies while the correlation between air pollution and local road traffic levels were in the order of 0,70. RFS Job distinguishes between Sound-, Environ- and Psychscape for the different worlds of importance for noise annoyance. The model linking only Soundscape (**NEIGH MAX**) and Psychscape (**SENS1** and **SENS2**) parameters to noise annoyance, will be affected by omitting Environscape variables, such as air pollution levels. A SEM model see figure 3 – right panel, can however, incorporate both relationships between noise exposure and noise annoyance, and between air pollution exposure and annoyance with the perceptible parts of air pollution – exhaust/odour and dust/grime.

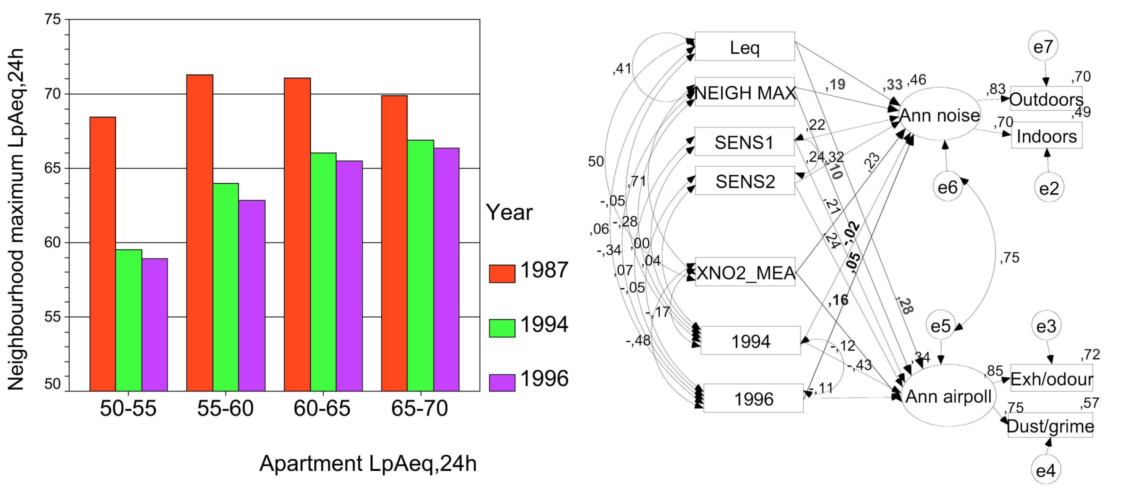

Figure 3: Average maximum of neighbourhood $L_{\mathrm{pAeq,24h}}$ values within 75 m of each respondent for different values of $L_{\mathrm{pAeq,24h}}$ at apartments before and after traffic flow reductions – left panel; model for noise and air pollution annoyance – right panel.

This SEM can be regarded as a "black box" model as many Psychscape variables are inadequately accounted for in the model and we lack direct links between the annoyance terms. The external paths are thus in lieu of a more comprehensive internal Psychscape model. It differs from single equation models through the linkage between the two error-terms **e5** and **e6**. The SEM model thus provides a stepping stone to a model linking the noise and air pollution exposure indicators to their respective direct annoyance impacts. At this stage such a model is not identifiable without incorporating additional relationships between Psychscape variables stabilising the model and making it possible to identify the effects of the different factors.

The result of the estimation of the SEM including air pollution as an explanatory variable for noise annoyance see figure 3, shows acceptable fit (GFI=0,92, RMSEA=0,04, Hoelter0,05=712). A model fixing the path coefficient from the air pollution indicator to road traffic noise annoyance to zero was rejected. The percentage of explained variance has been increased from 26 % in the regression model of figure 1, to 46 % in the model in figure 3 by the inclusion of Sounds- and Environscape variables, measurement errors and the correlation between the annoyance error terms in the model. The effectiveness of reducing noise levels at apartments is not as large as it would seem from models omitting air pollution and neighbourhood noise indicators (Path coefficient=0,33 instead of 0,51).

6 - CONCLUSION

To estimate the relative effect of different noise reduction and abatement strategies and their benefits in term of annoyance reductions it is necessary to distinguishing between the effects of noise, noise neighbourhood and other environmental exposures. General measures to move or reduce traffic will have effects on insecurity, air pollution, and noise levels both at people's home and in their neighbourhood thus reducing several annoyance-contributing factors at the same time. The effects of reduced tyre/road surface noise will on the other hand primarily reduce noise emissions, but not air pollution levels and insecurity.

While the SEM examples in this paper need to be developed further, they nevertheless illustrate that slightly different causal models can give quite different results when it comes to the efficacy of different types of noise abatement strategies. For SEM to be effective in estimating combined effects we need to provide a better map of the relevant Psychscape variables, obtain more precise indicators of the Sound- and Environscape factors and find out of how to bind it all together. To obtain simpler and more robust relationships we thus need to deepen our theoretical and methodological understanding and build more complex models.

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