External noise costs from transport - How are they estimated and how are they distributed within society?

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Abstract
It is well recognised that noise may cause or contribute to a variety of negative impacts on human well-being and health. The calculation of external costs allows to quantify the economic relevancy of these different noise impacts and to summarize them to a single monetary unit. Typically, external cost calculations do not reflect the distribution of impacts among the members of a society. In contrast, the here presented methodology aims at quantifying external noise costs for different socio-demographic groups in order to examine whether certain groups may be affected by noise more than others. For this purpose, data from strategic noise maps are used to compute external costs per exposed person on the level of street sections. Then, noise costs are overlaid with differentiated information about the social composition of neighbourhoods, especially regarding the share of inhabitants with migration background as well as the share of inhabitants receiving social welfare. The results show that noise exposure differs significantly between socio-demographic groups. Inequalities may exist dependent on the place of residence and may be combined with other burdens. The analysis, which combines approaches from environmental justice research with the concept of external cost calculation, tries to raise political awareness of equity issues in urban- and transportation planning.

1. Introduction
Motorized transportation causes a variety of environmental effects, of which community noise, among others, is directly affecting humans. In urban areas of developed countries, transportation is considered to be the main source for noise pollution. Noise impacts include e.g. annoyance reactions of inhabitants as well as an increased risk of health problems and premature death in case of chronic noise exposition.

Sound emission levels at the source depend on the number, type and speed of vehicles. Sound propagation in the environment then depends on factors like distance between source and receiver point, acoustic absorption of surfaces and reflection of objects like facades. All factors explain why noise exposure values differ a lot even on a very small scale. High noise values may occur on the facade facing a road used close to the maximum capacity, whereas the backside of the building may be undisturbed. For this reason, it is important to assess noise impacts on a local scale.

The study tries to quantify these negative external effects originating from all types of transportation noise in Berlin, Germany by monetizing them. It uses modelled noise data and estimates the economic burden (external costs) for all residents exposed to noise. This allows two different types of analyses: First, the often unconsidered economical effect of noise can be quantified and the need of noise mitigation measures can be better communicated to decision makers. Second, specific socio-demographic groups can be compared regarding the burden of noise they have to bear. The emphasis of this paper is on the second type, trying to transfer methods of environmental justice research into the field of external cost calculation. Socio-demographic groups in society which have to bear more or less effects from noise are identi-

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fied. The type of analysis can help to detect the unequal distribution of environmental burden (e.g. hot spots) where generally depressed areas are accompanied by poor environmental quality.

2. Literature review

The analysis of the social distribution of environmental pollution is still an evolving topic in European research (Fairburn 2008). It is based on the large body of environmental justice research in the United States. Nonetheless, it can be noted, that existing European research has a different focus: racial differences seem to be a less important topic, probably due to a less pronounced degree of segregation.

In Germany, research in this area has mainly focused on public health topics (Helmer 2000, Mielck 2000). Only recently, social sciences, planning authorities and politics are starting to address the topic (Klimeczek 2011).

Early empirical studies for Germany use data from national representative surveys to correlate perceived exposition to environmental pollution or housing conditions with socio-demographic characteristics of respondents (Hoffmann 2003, Mielck 2004, Kohlhuber 2006).

Subsequently, research methods based on Geographic Information Systems (GIS) have been introduced gradually. They combine objective modelled noise exposure data with spatially coded information about a population's socio-demographic characteristics. For Berlin and also Hamburg, pilot studies have been conducted using this type of approach (Gaffron 2010, Lakes 2011, Becker 2011).

All but one (Lakes 2011) of the here cited studies found some relationship between socio-demographic characteristics and perceived noise exposition as well as proximity of housing to major roads or objective modelled noise exposition. However, most authors accentuate the need for further research and the exploratory character of their studies (Gaffron 2011).

In conclusion, the empirical evidence regarding the correlations between socio-demographic groups and noise exposure is still low. Objective measures and modelled data are increasingly used. However, analyses so far have been conducted on the level of statistical districts only. Especially for noise, analyses on a much smaller scale might be necessary to be able to evaluate exposure differences between socio-demographic groups. This paper tries to overcome this shortcoming by using exposure and socio-demographic data on the level of street sections.

3. Methodology

3.1 Estimation of external cost factors

Noise costs have been calculated using the economic concept of external costs as summarized in (Maibach 2008). It follows the concept that users of the transport system generate negative effects which affect primarily third persons like residents. The effects of the generated noise are not born by transport users, meaning that they are not taken into account when making travel decisions. Therefore they are defined as external effects. By valuing the costs of damages, mitigation and prevention, the external effects can be converted into a monetary amount called external costs. The methodology for such estimates is well accepted in economics.

A detailed description of the methodology used to calculate external noise costs for our analysis can be found in Gerike 2012 and Becker 2012. The applied cost factors shown in Table 1 include a monetary valuation of health effects. With higher noise levels in the unit decibel (dB(A)), the cost factors increase.

For health effects, the diseases with the best epidemiological evidences Acute Myocardial Infarction (heart attack), other Ischaemic Heart Disease and Hypertension (high blood pressure) are included in the estimation (Babisch 2006). The causal relationship of disease occurrence and noise exposure is usually described by dose-response-functions from epidemiological studies. The dose-response-functions state the
increase of risk to suffer from a health outcome of an exposed population group in comparison to an unexposed population group, always fully isolated from other influencing factors. For an exposed population, the number of additional disease occurrences attributable to noise exposure can be derived. The following methods are used for estimation of cost factors for health outcomes:

- The German health statistic provides information about the costs of medical treatments, prevention and rehabilitation, both paid by health insurances and self-paid (Destatis 2010b). The costs have been disaggregated in a top-down process to particular health outcomes. We divided the given total cost with the disease occurrence per year and derived the costs per case. This can be transformed into the cost factors below.
- The German health statistic also provides information about the number of sick leaves and early retirements, disaggregated by health outcome. Their economic burden is determined by multiplication with the Gross Domestic Product per employee.
- The number of fatalities per particular health outcomes can be derived from the cause-of-death statistic. Again, a fraction can be associated to noise exposure. A value of 50,000 Euro is derived from literature sources (Maybach 2008) for the “value of a life year lost” (VLYL) and the total economic loss by premature death can be estimated.

Besides health effect, annoyance by noise is the second main component of external noise effects. It has to be assessed additionally to health costs because the general public is unaware of the long-term-health effects caused by noise. Two approaches are generally used in literature: revealed preference (hedonic pricing) and stated preference surveys. The revealed preference analyses the functional relationship between rental prices and characteristics of the apartment including the noise exposure. In contrast to that, stated preference surveys identify the willingness-to-pay by econometric models used on results of special surveys. Both approaches have advantages and disadvantages and we decided to use results from stated-preference surveys in the literature. This consideration is fully supported by official guidelines (Maibach 2008, Umweltbundesamt 2007).

Table 1
External health and annoyance costs (Euro, price base: 2008) from noise per exposed individual in Berlin
Source: Becker 2012

<table>
<thead>
<tr>
<th>LDEN in dB(A)</th>
<th>Health cost</th>
<th>Mortality</th>
<th>Annoyance</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Myocardial Infarction</td>
<td>Ischaemic Heart Disease</td>
<td>Hypertension</td>
<td></td>
</tr>
<tr>
<td>&lt;55</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>55 - 60</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>76</td>
</tr>
<tr>
<td>61 - 65</td>
<td>0</td>
<td>1</td>
<td>27</td>
<td>315</td>
</tr>
<tr>
<td>66 - 70</td>
<td>2</td>
<td>6</td>
<td>72</td>
<td>360</td>
</tr>
<tr>
<td>71 - 75</td>
<td>5</td>
<td>13</td>
<td>116</td>
<td>532</td>
</tr>
<tr>
<td>76 - 80</td>
<td>9</td>
<td>25</td>
<td>164</td>
<td>684</td>
</tr>
</tbody>
</table>

3.3 Calculation of external costs

Noise exposure data have been taken from the strategic noise map of Berlin which is publicly available online. This map is based on sophisticated modelling and serves as a base for all noise mitigation planning of the city administration. Noise immissions in the map have been calculated in 2008 for 3,910,391 fictitious receiver points equally distributed on the outside of all buildings facades (see Figure 1). They are 4 m above ground level and their number varies depending on the building size (SenStadt 2008). For modelling the strategic noise map, different input parameters like 3-D-building shape, road surface and number
of vehicles were taken into consideration. The results clearly do not regard all special cases like noise in the 5th floor, inside the rooms or peak hour, but they are the best data currently available and the methodology is legally legitimated.

![Figure 1](image)

**Figure 1**
Example for receiver points distributed on building facades
Source: Screenshot from ArcGIS

Different attributes are attached to each receiver point, including separate noise levels from all transport modes as well as the total noise level, a building identifier and the number of inhabitants per receiver point. The number of inhabitants at each receiver point has been derived from statistical data on block level (base year: 2005). Block inhabitants have been distributed proportionally to the buildings of the block according to the floor area (SenStadt 2008). Within a building, inhabitants have been assigned evenly to the receiver points.

External costs per receiver point have been calculated for all receiver points with sound immission levels above 55 dB(A). Then, external costs have been summed up for each building.

In a last step, the external costs per building have been aggregated to the level of street sections by using the building identifiers. The building identifiers also allowed the calculation of the number of inhabitants for each street section and thus mean external noise costs per capita on the level of street sections.

### 3.4 Description of socio-demographic characteristics

The socio-demographic characteristics of population groups can be described by a variety of different variables. Gender, age, citizenship, level of education, equipment with communication devices or different forms of household income are typically used in surveys (Destatis 2010). Sometimes a combination of individual variables is used to form an aggregate indicator. For Berlin, an indicator (SenStadt 2009) including, among other variables, unemployment rate, has been used on the level of statistical districts for former studies (Becker 2011). Such broad indicators are not available on a further disaggregated local level.

In our analysis, we are especially interested in the relationship between financial power (income) of a household and the noise costs at the chosen dwellings. We are also interested in the influence of ethnic
origin, namely in the question, whether certain ethnic groups are systematically exposed to higher noise costs. Data concerning these socio-demographic variables are not available on the level of street sections. For this reason, we used two variables serving as (slightly fuzzy) proxy for the named characteristics of interest: the fraction of individuals “dependent on social welfare” and the fraction of individuals with “migration background”.

“Migration background” is a specific term defined in the German statistic which includes foreign citizens as well as German citizens who are for example first- and second-generation immigrants. The calculation of the fraction of people with migration background is based on the total number of inhabitants of a street section. The definition of the term “dependent on social welfare” includes all individuals living in households which receive social benefits from the government according to act “SGB II” to ensure a minimum standard of living. Employable individuals between 15 and 65 years are entitled to the benefits (Arbeitsagentur 2009). The fraction of social welfare recipients is based on the total number of inhabitants of a street section below the age of 65 years.

We use information about the proportion of people with “migration background” and “dependent on social welfare” in the total population. This information does not directly allow to assign individuals to socio-demographic groups. Nonetheless, we believe that these indicators can serve as a proxy for the underlying socio-demographic groups, since they express the probability of one individual inhabitant of a street section to belong to a socio-demographic group of interest.

3.5 Environmental Justice Analysis

The combination of noise level data, external cost factors and socio-demographic data requires the use of different data sources, which are merged on the level of street sections.

Besides the cost factors introduced in section 3.1, the following data sources provided by the City of Berlin have been used for the analysis:

- Strategic noise map with $L_{DEN}$ which is a noise indicator combining the noise of day, evening and night. The noise map is in accordance with European Noise Legislation (European Parliament 2002). As an additional feature it comprises cumulative sound levels of road, air and railway traffic noise (added energetically) which are used in the analysis (SenStadt 2008).
- A database containing the allocation of building identifiers to street sections. Street sections are a given classification and generally include all buildings between two intersections. At the road intersections, the allocation of corner buildings depends on the orientation of the street address (Statistic 2011a).
- Socio-demographic data on the level of street sections. The data include the number of inhabitants (2010), the fraction of inhabitants below age 65 dependent on social welfare (base year: 2009) and the fraction of individuals with migration background (base year: 2010). The fractions are aggregated to 10% intervals. For street sections with less than 50 inhabitants no socio-demographic data are available for data protection purposes (Statistik 2011b).

External noise costs are calculated based on immission levels and the number of inhabitants from the strategic noise map. The relationship between external costs and the social composition can then be analysed on the level of street sections.
4. Merging external noise costs and social data

The external costs per street section have been linked directly to the socio-demographic data. Naturally, not all buildings and their costs could be assigned to street sections: a share of 0.68 % of the costs could not be assigned to street sections in our study, most likely because of changes of the urban infrastructure over the years. Another 12.31 % of the costs (18.02 % of the inhabitants, 57 % of street sections) could be assigned to street sections, but no socio-demographic data are available for them, most likely because of the cut-off value for the minimum number of inhabitants per street section.

At this point of analysis, numbers of inhabitants have been available from two different sources: the originally block-based data from the strategic noise map and the statistics of socio-demographic characteristics for street sections. The number of inhabitants provided by the strategic noise maps is about 20 % higher than the respective number from the socio-demographic statistic due to the reasons stated above. Since noise costs have been calculated using the number of inhabitants from strategic noise mapping, this data source is also used for the statistical calculations.

5. Results

According to official statistics, the total number of inhabitants living on social welfare is 593,079 (2009) (Arbeitsagentur 2012), which corresponds to 17.6 % of all inhabitants. The total number of people with migration background is 872,132 (2010) (Statistic 2011c), which corresponds to 25.7 % of all inhabitants.

Table 2 shows (among other things) the distribution of welfare recipients among street sections. The table reveals that to at least some extent, segregation between the socio-demographic groups exists with half of the population living in street sections with either a disproportional small or disproportional big fraction of social welfare recipients. For people with migration background, even two third of the population is living in street sections with either a disproportional small or disproportional big fraction.

Table 2
External noise costs (mean and median) per inhabitant in Euro (2008) by fraction of social welfare recipients living in the street section
Source: own calculation

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Group size</th>
<th>Noise cost - mean</th>
<th>Noise cost - median</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 10 %</td>
<td>481,891</td>
<td>80.44</td>
<td>18.06</td>
</tr>
<tr>
<td>10 to &lt; 20 %</td>
<td>789,271</td>
<td>110.51</td>
<td>48.41</td>
</tr>
<tr>
<td>20 to &lt; 30 %</td>
<td>618,887</td>
<td>136.20</td>
<td>64.50</td>
</tr>
<tr>
<td>30 to &lt; 40 %</td>
<td>434,361</td>
<td>147.55</td>
<td>75.56</td>
</tr>
<tr>
<td>40 to &lt; 50 %</td>
<td>243,483</td>
<td>154.75</td>
<td>83.20</td>
</tr>
<tr>
<td>50 to &lt; 60 %</td>
<td>119,465</td>
<td>154.50</td>
<td>79.85</td>
</tr>
<tr>
<td>&gt; 60%</td>
<td>50,263</td>
<td>155.09</td>
<td>102.35</td>
</tr>
<tr>
<td>not attributable</td>
<td>601,623</td>
<td>88.40</td>
<td>5.14</td>
</tr>
</tbody>
</table>
In the next step, we analysed the distribution of noise costs. Mean noise costs per capita have been calculated on the level of street sections. The average noise costs per capita vary between 0 and around 1,300 Euro. The mean per capita is 117 Euro while the median is 41 Euro. Figure 2 shows the proportion of the total external noise costs that is cumulatively borne by a certain proportion of the population. About 25 % of the Berlin population does not bear any external traffic noise costs. For them, noise exposure is (on average) below 55 dB(A) or not available. There is a relative big difference between the median and the mean value of the noise cost distribution. The distribution is positively skewed, leading to a highly unequal distribution of noise costs among the population with approximately 25 % of the population bearing around 75 % of the costs.

Figure 2
Cumulative external cost by proportion of the population
Source: own calculation

The analysis of the relationship between the here used socio-demographic variables and external noise costs reveals a relationship between migration background and social welfare recipients. We compared the mean and the median of external noise costs per capita for the described socio-demographic groups. As shown in Figure 3 and Table 2, the mean and the median of external noise costs per capita differ strongly and are higher for people living in streets with high shares of inhabitants with migration background (respectively living on social welfare). The difference in external noise costs amount to a factor of 2 between the group with the lowest share of welfare recipients, respectively people with migration background compared to the group with the highest shares.
6. Discussion

In section 5 we presented first results of our analysis of small-scaled socio-demographic and noise exposition data from Berlin. We could show that noise costs are not distributed evenly among the inhabitants of Berlin. While 25 % of the population do not bear any costs at all, another 25 % bear approximately 75 % of the costs. We also found that the burden of noise varies systematically between different socio-demographic groups. We identified a relationship between socio-demographic variables and external noise costs per capita. This result does not appear to be to implausible, especially since people choose their dwellings considering many factors (proximity to working places, social facilities, transport infrastructure). A lack of financial power certainly restricts potential dwellings to cheaper locations, but only part of those will be noisy. On the other hand, at least some of the more affluent individuals might prefer living in the city center, thereby gaining easy access to a variety of facilities, however bearing higher noise costs, too (Mitchell 2003). Additionally, the rather broad and somehow fuzzy definition of the used socio-demographic variables might conceal some of the dependencies existing in reality.

As shown before, we could show that mean noise costs per capita increase by a factor of 2 between the groups with the fewest share of welfare recipients compared to those groups with the highest shares. The same results could be found then comparing social noise costs for groups with low versus groups with high shares of people with migration background. These results clearly state the relevance of addressing existing inequalities in noise exposition.

Figure 3
External noise costs per inhabitant in Euro (2008) by share of individuals with migration background living in the street section
Source: own calculation
7. Conclusion and outlook

In conclusion, the presented analysis is the first of this kind for Berlin. We have been able to use exceptional small-scaled data on the level of street sections. The analysis confirmed previous studies stating a small but consistent correlation between variables aiming to express the social status as well as ethnic origin of an individual and exposition to noise. In this sense, the study can be seen as an important contribution to our empirical knowledge regarding environmental justice issues in urban environments. Using external noise costs as an instrument to “weight” severity of noise exposition is a novelty in the field of environmental justice analysis. By expressing noise exposition in monetary terms, we are able to compare the severity of different noise burdens on an arithmetic scale. This is quite an advantage when otherwise having to work with logarithmic sound level data. It also stresses the importance of noise mitigation measures by showing that mean noise costs per capita are twice as high for the least advantaged groups in comparison to the most advanced groups.

To confirm and substantiate those results based on average values, we plan to further analyse our database with the help of a more advanced statistical model. Additionally, we work on improving the socio-demographic information available to us. On the one hand, the variables we now use for expressing financial power and ethnic origin of groups are far away from being precise indicators of the characteristics of interest. On the other hand, we did not include other important variables in our analysis so far (namely education, age distribution, see e.g. (Gaffron 2012, Mitchell 2003). These shortcomings will be addressed in further research. In order to protect all inhabitants equally from excessive noise burdens further research is also necessary to reveal the sources of the found correlation between migration background and noise exposition.

Bibliography


