Benefits of noise measure in train commuting suburbs – A comparison of Swedish guidelines and WHO recommendations[1]

Jan-Erik Swärdh
VTI – Swedish National Road and Transport Research Institute

Abstract
In this study, we compare different valuation functions for a noise abatement measure in an exploitive train commuting suburb in Sweden. The benefits are estimated with different functions focusing on Swedish guidelines and recent WHO recommendations. The results show that the willingness-to-pay-based estimates of the Swedish guidelines are much lower than the estimates based on WHO guidelines. The main reason for the higher benefit estimates with WHO recommendations is the discontinuous valuation function that leaps from 0 to about 5000 SEK at 49 dB, whereas the Swedish guidelines does not include any corresponding discontinuity in its valuation function. Furthermore, the WHO recommendations are sensitive to night exposure as the cost of sleep disturbance is dominating. These different results of the monetary benefits illustrate the importance of including only established impact functions and valuation functions, and carefully apply them when noise-abatement benefits are calculated.

Keywords: Noise, Benefit, Property values, Valuation function, WHO

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1. Introduction

Urban traffic noise is an important environmental problem in the modern society. For example, at least 100 million people are affected by road noise in the European Union today (WHO, 2018). Increased urbanization may worsen the noise problem, as more people will be exposed, but also as traffic volumes increase.

Even transport modes that are seen as sustainable, e.g. train, suffers from noise problems. In terms of CO_2 and emissions like particulate matters and NO_x, an increased number of citizens and high share of train commuters is sustainable, but increased train traffic and densification may lead to higher noise exposure. This issue can be illustrated by the trade-off between agglomeration and accessibility benefits and noise exposure in train commuting suburbs. Rail transport are expected to result in environmental benefits like low environmental pollution and carbon emissions (WHO, 2018). Still, it remains a major source of local noise pollution and, thus, there is still a need of studying noise-reducing measures.

These increased costs may be mitigated by noise-abatement measures as noise barriers or housing insulation. One way to analyze the impact of noise measures is to perform a cost-benefit analysis (CBA), which is an accounting of all society costs and benefits, monetary as well as non-monetary, related to the given measure, and expressed in monetary terms. The CBA is a powerful tool as it states whether a measure will increase social welfare, i.e. the benefits of the measure exceeds the costs of the measure.

In this study, we will focus on the benefit side of noise measures in train commuting suburbs. Specifically, the purpose is to compare different valuation functions, estimating the benefits of a noise barrier in an exploitive train commuting suburb. Most of the paper will focus on the differences between valuation functions and the inclusion or exclusion of, more or less, established health outcomes of noise exposure. In addition, we will relate the benefits to increased property valuation when the noise exposure level is decreased.

No account is taken to exposure from other traffic noise, e.g. road noise; we only study measures regarding rail noise and these will likely not impact the noise exposure from road sources. However, high exposure from road noise may lead to other perceived disturbance from rail noise. Thus, we have checked the existence of high-traffic roads close to the analyzed area. No road with an extremely high traffic flow is located close to the analyzed area. One road (Torsbyvägen) relatively close has an annual average daily traffic of 14500 vehicles (ÅF, 2014), which may cause some problems with road-noise disturbance.

We do not analyze the cost of noise measures and thus not complete a formalized cost-benefit analysis (CBA). In this paper, we only analyze one given noise measure and deeply analyze its benefits. Still, we will compare these benefits with estimated cost as an illustrative example.

The paper is disposed as follows. In the next section, the valuation method of environmental amenities such as railway noise is presented. In Section 3, the estimated benefits of noise abatement measures are presented. Finally, the paper's result is discussed, and conclusions are presented, in Section 4.

2. Method

The method used to calculate noise-measure benefits in this study is based on the impact pathway approach (IPA), which is an established principle for valuation of costs and benefits of environmental externalities (see the ExternE project described in, e.g., Friedrich and Bickel, 2001). Briefly expressed, IPA consists of different steps to finally end up with monetary estimates. First, the noise emissions are calculated, followed by estimation of the impact of the noise exposure by the use of impact functions. Subsequently, a monetary valuation function, usually willingness-to-pay based, for each impact of the noise exposure is used to calculate the monetized cost. In all these steps, established models and functions are required.

To estimate the benefits of noise-abatement measures we need to know their impact on noise, i.e. noise calculations, and the valuation of noise reductions. In this study, we will go through different valuation functions and different assumptions to analyze how sensitive the estimated noise abatement benefits are with respect to these different functions and assumptions.

2.1. Noise Calculations

The object of our case study is the small town of Ytterby in Sweden. Ytterby is located along a railway line about 18 kilometers north of Gothenburg, the second largest city of Sweden, with a potential of a large increase of train commuting from Ytterby to workplaces and educations in Gothenburg. Therefore, Ytterby is defined as a potential train commuting suburb, where densification has a potential to lead to more climate friendly and efficient transports.

The noise is calculated as A-weighted equivalent noise levels, L_{Aeq24h}, at the dwelling façades with the assumption of 2,8 meters per floor. The calculations from different noise scenarios are conducted using the model NORD2000 and has a high resolution with separate noise calculations at the façade for each 2,5 meters horizontally. 5495 such noise points are calculated. Furthermore, the noise calculations are defined in the 24-hour equivalent level, $L_{\mathrm{Aeq,24}}$, since the official Swedish valuation of noise costs (Swedish Transport Administration, 2018) is defined using this noise indicator.

As the noise indicator used in WHO (2018) is the day-evening-night indicator (L_{den}) or the night indicator (L_{night}), we need to translate our indicator (see, e.g., WHO, 2018, p. x-xi for a description of different noise indicators). According to Beck et al (2018):

$L_{\mathrm{den}} \approx L_{\mathrm{Aeq,24}} + 6$, and

$L_{\mathrm{night}} \approx L_{\mathrm{Aeq,24}} - 1$.

However, for a Swedish context, especially when there is a relatively moderate amount of night traffic, a more relevant rule of thumb would be as follows based on WHO (2011):

$L_{\mathrm{den}} \approx L_{\mathrm{Aeq,24}} + 2$

Therefore, we also approximate:

$L_{\mathrm{night}} \approx L_{\mathrm{Aeq,24}} - 5$.

The noise exposure is calculated for two scenarios, one without a noise barrier and the other one including a noise barrier that is placed on the east side of the rail track through Ytterby. The noise barrier is placed 5 meters from the center of the track with a height of 4 meters. Furthermore, the noise barrier starts at the closest crossing south of Ytterby railway station and is ended at road 168 north of the station.

In addition, we have assumed 0,4 individuals for each calculated façade point. This assumption is based on the relation between the number of individuals registered to live in a few of these dwellings located close to the railway and the number of façade points of these dwellings.

We estimate the noise abatement benefits using a reference scenario where the commuter trains run every 15 minutes in both directions during peak hours. Thus, note that both these scenarios include a large increase of the rail traffic compared to the current situation. As the traffic today is relatively low, a noise barrier would only be considered if the traffic is increased as Ytterby will be developed to a train commuting suburb.

2.2. Monetary valuation of noise

An important contribution of this paper is to compare different kinds of impact functions and valuation functions for traffic noise abatement. As there are well-established Swedish national guidelines for how to conduct CBA in the transportation sector (Swedish Transport Administration, 2018), we will have these guidelines as the basis for our comparison. The Swedish guidelines are throughout the paper referred to as ASEK, which is the Swedish acronym for “working group for cost-benefit analyses”.

Furthermore, the other impact functions and valuation functions will be based on recent guidelines from WHO (2018). These guidelines are based on impact and/or relative risks at different exposure levels expressed in disabled weights (DW), which is a measure of living quality for an individual during a year. This is different compared to ASEK, where there are yearly willingness-to-pay estimates per individual given for each level of noise exposure.

More about the method and assumptions for each example of monetary valuation is given in the Sub Sections below. The first two monetary valuation examples (ASEK and WHO without IHD) are the most important ones for our comparison, while the two others can be more treated as a kind of sensitivity analysis. In addition, in Section 4 we present a discussion about the implications of our results.

2.3. ASEK

The official Swedish guidelines ASEK (Swedish Transport Administration, 2018) is based on a yearly cost per exposed individual at different levels of $L_{\text{Aeq},24}$ starting at 50 dB. This valuation function is based on previous valuation studies of single-family houses with an additive term for additional adverse health effects (see Swärdh et al., 2012; Swedish Transport Administration, 2018), where the latter starts at 58 dB $L_{\text{Aeq},24}$. The cost of adverse health effects amounts to a relative small part of the total cost, for example 4,5 percent at 60 dB $L_{\text{Aeq},24}$ and 12,5 percent at 70 dB $L_{\text{Aeq},24}$ (see Swedish Transport Administration, 2018, Table 10.4).

Note that the two last steps of IPA, as described in the beginning of Section 2 above, i.e. the impact of noise exposure and the monetary valuation, are integrated into the same step, which is the estimation of the property-value change due to a noise-exposure change.

Furthermore, the cost of noise exposure is composed into indoor noise exposure and outdoor noise exposure. This could be important, for example when the measure is a façade insulation. In our study, however, we will study a noise barrier and such a noise-abatement measure will be reducing the noise level both outdoor and indoor.

The ASEK report of 2018 (Swedish Transport Administration, 2018) presents the costs in 2014 years prices. We adjust these costs to the latest available price year that is 2018. As the noise costs are based on willingness-to-pay estimates, they should be adjusted by using consumer price index and increases in real income per capita (Swedish Transport Administration, 2018). By using such data of Statistics Sweden, the adjustment is an increase from 2014 to 2018 of 4.8 percent for consumer prices and 6.2 percent for real incomes.

In addition, we use the ASEK valuation to estimate the increased property value due to the noise barrier for all affected dwellings on an aggregated level and, also, two different dwellings located close to railway – one single-family house and one apartment building.

The increased property value is estimated based on the dwelling-specific noise calculations and the actual number of people registered to live in the dwellings. Furthermore, we here use the perpetual value instead of 40 years as there is no reason to believe that a noise barrier will be removed in the future implying that the perpetual benefits can be assumed to be capitalized into the property market.

2.4. WHO without ischemic heart disease (IHD)

The WHO report (2018) describes several adverse health effects that are caused by noise exposure. Here, we exclusively rely on the effects of rail-noise exposure. The effects that are reviewed in WHO (2018) are annoyance, sleep disturbance, incidence of ischemic heart disease (IHD), incidence of hypertension, permanent hearing impairment, and reading skills and oral comprehension in children.

For annoyance and sleep disturbance there are recommended impact functions that we will use in our study. For IHD, the impact function is rated very low quality by WHO (2018), but we will still use the impact function of this adverse health effect as a sensitivity analyses described in Section 2.5. Incidence of hypertension is excluded as there is no usable impact function. Regarding permanent hearing impairment and reading skills and oral comprehension in children, WHO (2018) concludes that there is no evidence available.

The impact function for annoyance is defined in the following way. The lower limit for adverse health effects is set to 54 dB L_{den} (WHO, 2018, p. 49). In addition, we use the impact function for the percentage of exposed individuals that is highly annoyed (HA) derived from the systematic review of Guski et al. (2017) (WHO, 2018, p. 49):

$$\%HA = 38.1596 - 2.05538 \times L_{\mathrm{den}} + 0.0285 \times L_{\mathrm{den}}^2$$

The impact function for sleep disturbance is defined in the following way. The lower limit for adverse health effects is set to 44 dB L_{night} (WHO, 2018, p. 49). In addition, we use the Table 22 of WHO (2018, p. 56) to define the percentage of highly sleep disturbed (HSD) individuals in 5-dB intervals.

To be able to estimate the cost of these effects in monetary terms we use the disability weights (DW) of Table 3 in WHO (2018, p. 18) – 0.02 for HA and 0.07 for HSD – combined with the valuation of a quality-adjusted life year (QALY) that is approximated with the value of a lost life year (VOLY) derived from the value of a statistical life (VSL) in Swedish transport guidelines (Swedish Transport

Administration, 2018). The risk component of VSL is 40,5 million SEK in 2014 years prices. Using the interest rate of 3,5 percent and an assumption of 40 lost life years per lost statistical life (see Swärdh and Genell, 2016, p. 18), and adjusted to 2018 years prices, one QALY is valued 1,9 million SEK.

2.5. WHO including IHD

Here, we will add an effect of increased risk for IHD in our WHO estimates of the former Sub Section. Although this impact function is rated very low quality by WHO (2018), it is interesting to see the relation between costs of IHD and costs of sleep disturbance and annoyance. The underlying argument is the hypothesis that low-quality rating of IHD for rail noise, which is a difference compared to road noise, is mostly a result of the rather few studies available and not a result of no risk of ischemic heart disease from rail noise exposure.

We use the point estimate of relative risk (RR) 1,18 from WHO (2018, p. 52). This estimate is not statistically significant but the argument for our inclusion of this effect is that the insignificant effect is a result of few studies. Furthermore, we use the road-noise recommendation that the risk of cardiovascular decease starts at the exposure level of 53 L_{den}. Also, the RR of 1,18 is per 10 dB increase and we use the statistics of the Swedish national level from 2017 (Socialstyrelsen, 2018) as the baseline risk for IHD.

In addition, we use two different approaches to value the cost of IHD in monetary terms, both of them based on the increased risk of IHD described above. The first is to use the DW of 0.405 as given in WHO (2018, Table 3) combined with the QALY valued 1,9 million SEK as described in Sub Section 2.4. above.

The other one is a more complex structure of different impacts of an increased risk of IHD taken from the valuation of noise health effects in Swärdh and Genell (2016, Section 2.3). Included here are lost life years of myocardial infarction, days of hospitalization of myocardial infarction, days of work absence of myocardial infarction, and disutility of a non-fatal myocardial infarction. The number of lost life years per fatal myocardial infarction is assumed to 13.2, which is based on the calculation example of WHO (2011, p. 25). A useable average number of hospitalization days and work absence days are not found in WHO (2011). Instead we use the relations in ExternE (Bickel and Friedrich, 2005), which is 18 days of hospitalization and 320 days of work absence for each non-fatal case of myocardial infarction. Note that we also adjust these functions with the factor 0.796, as the relative risk is defined for adults and this factor is the share of all Swedish individuals in 2014 that were 18 years and older.

Finally, we also need a brief discussion about the fact that IHD is included in the ASEK valuation (based on WHO, 2011), but differs largely compared to the IHD valuations that are based on WHO

(2018).This is mainly due to two effects: the impact occurs at much lower levels of noise exposure than previously assumed and the level of VOLY in Swedish guidelines is higher nowadays. The first-mentioned effect is the most influential and potentially very relevant for Sweden, as a substantial share of people that are noise exposed are subject to relatively low, but still potentially health-affecting, noise levels. Note, however, that the assumed impact function used here is rated as "very low quality" by WHO (2018) meaning that this result should be treated as a calculation exercise.

2.6. WHO with much less night traffic

As our case is about a development of a train commuting suburb, there could be reasons for the traffic during night to be relatively low. Thus, we here as a sensitivity analysis change the assumption of $L_{\text{night}} \approx L_{\text{Aeq,24}} - 5$ to $L_{\text{night}} \approx L_{\text{Aeq,24}} - 10$.

This alternative assumption is somewhat arbitrarily chosen but recall that the purpose is to analyze the sensitivity of night-time exposure for the total noise cost and the estimated benefit of a noise barrier.

As we assume that highly-sleep-disturbed (HSD) individuals starts at 44 dB L_{night}, which was at 49 dB $L_{\text{Aeq,24}}$ before, this will now be at 54 dB $L_{\text{Aeq,24}}$.

In all other aspects, we follow the specification in Section 2.4., that is the WHO impact functions without IHD.

3. Estimated benefits

In this Section, we present the estimated benefits from the noise barrier in the train commuting suburb of Ytterby about 18 kilometers north of Gothenburg.

3.1. Noise-exposed individuals

In Table 1, the number of exposed individuals at different noise levels is presented. The number of exposed individuals at different noise levels decreases significantly when the noise barrier is built. As an example, 375 individuals are exposed to at least 49 dB $L_{\text{Aeq,24}}$ in the case of no noise barrier. With a noise barrier, this number of individuals decreases to 217. Individuals exposed to at least 55 dB $L_{\text{Aeq,24}}$ is at the same time 88 without a noise barrier compared to 58 with a noise barrier. Note also that the barrier is built on the east side of the railway meaning that people living west of the track, e.g. those with 60-61 dB, will not benefit from the barrier.

Table 1 - Number of exposed individuals at different noise levels

$L_{Aeq,24}$ in dB	No of exposed individuals without Barrier	No of exposed individuals with Barrier
49	78	39
50	67	26
51	38	27
52	48	28
53	28	18
54	28	22
55	26	18
56	14	18
57	18	10
58	18	4
59	6	2
60	4	4
61	2	2

3.2. ASEK

In Table 2, we can see the estimates summarized in total benefits for the different scenarios using the ASEK valuation function. Firstly, we can observe that the yearly benefit of a noise barrier in Ytterby is valued about 120 000 SEK (11 SEK ≈ 1 EUR). The largest cost is found in the interval 54-58 dB, which is a combined result of the relatively large number of exposed individuals in this interval and the relatively high cost per exposed individual in this interval.

Table 2 – Valuation of noise cost with ASEK per year in SEK and 2018 years prices

$L_{Aeq,24}$ in dB	Yearly cost without Barrier	Yearly cost with Barrier
50	4625	1844
51	8099	5797
52	20726	12090
53	20295	13047
54	30614	23616
55	40527	27632
56	29554	36943
57	47612	26451
58	62314	14901
59	26810	8378
60	22422	22422
61	12186	12186
Total	325785	205309
Yearly benefit with barrier	120476	
Total benefit with barrier (40 years calculation period)	2572770	
Total perpetual benefit with barrier	3394811	

When we use the recommended calculation period of 40 years for local noise barriers and the recommended discount rate of 3,5 percent, the total benefit of the noise barrier is somewhat 2,57 million SEK. This benefit is much lower than the investment cost of a 700-meter noise barrier in the Swedish Transport Administration guidelines, which is about 10 million SEK.

In the bottom row of Table 2 the total perpetual benefit of the noise barrier is presented. This benefit of about 3,4 million SEK can be seen as an aggregate estimate of the increased property value of the housing properties that are affected by the noise barrier. Note that this estimate is adjusted for the adverse health effect included in the ASEK valuation from 58 dB $L_{\mathrm{Aeq,24}}$. Also, if some of these dwellings are rented apartments, this increased property value could be an overestimation as the benefits for the apartment renters cannot be incorporated in the rents (rent control). On the other hand, other buildings except dwellings are not included in the analysis.

A further analysis of property values can be made at the individual property level to see how large the effect of the noise barrier might be. These results can be found in Table 3. Note that these estimates do not consider whether the benefits could be capitalized into the property market (see the statement about rent control and rented apartments above). We can see that for these examples the benefit is much higher for the single-family house than for the apartment building. This depends solely on the higher exposure level for the single-family house without the barrier. Indeed, this house is one of the most noise exposed in Ytterby and also a house that experience one of the largest noise reductions with the barrier.

Table 3 – Increased property valuation with the noise barrier in 2018 years prices

	No of dwellers	**Highest exposure level without noise barrier**	**Highest exposure level with noise barrier**	**Yearly benefit**	**Perpetual Benefit**
Single-family house	4	57,5 dB	42,4 dB	18605	531585
Apartment building	37	52,1 dB	44,7 dB	2665	76150

Furthermore, the perpetual benefit assuming an interest rate of 3,5 percent is some 530 000 SEK for this single-family house. This is about 17 percent of the current property value according to the website www.booli.se. Then we have neither included, compared to the current property value, the cost of more noise in the reference scenario nor the benefit of increased accessibility to Gothenburg.

3.3. WHO without IHD

In Table 4, we can see the estimated benefits for the WHO valuation functions except IHD. In particular, this means that we calculate the noise costs of sleep disturbance and annoyance and treat these parts as additive. For a simpler interpretation and possible comparison, we thus present these parts separately in Table 4.

Firstly, we compare the cost of sleep disturbance with the cost of annoyance and can observe that the sleep disturbance costs are about 2.5 times higher than annoyance cost. This result coincides fairly well with the estimation of total noise costs of WHO (2018, p. 2) where sleep disturbance is the clearly highest part.

More interesting though, is the extreme difference with the ASEK cost presented in Section 3.2. In fact, the cost based on these WHO impact functions is more than 10 times as large as the ASEK cost. This difference is mostly due to two additive parts in the WHO costs, but also when we only study annoyance, which is a part that clearly is expected to be included in the ASEK costs, there is a large difference. The annoyance cost of WHO is somewhat 3 times as large as the ASEK costs. This difference depends on the much higher cost derived from the WHO function regarding relatively low noise levels. As an example, not presented in our Tables, the annoyance cost per exposed individual at 52 dB $L_{Aeq,24}$ is 432 SEK in the ASEK valuation compared to 3905 SEK in the WHO valuation. This comparison will be more elaborated in Section 3.6.

Table 4 – Valuation of noise cost with WHO functions per year in SEK and 2018 years prices

$L_{Aeq,24}$ in dB	**Yearly cost without Barrier**			**Yearly cost with Barrier**		
	Sleep disturbance	**Annoyance**	**Total**	**Sleep disturbance**	**Annoyance**	**Total**
50	1137735	-	1137735	596425	-	596425
51		-	-		-	
52		187417	187417		109327	109327
53		120511	120511		77471	77471
54		132301	132301		102061	102061
55	961909	136430	1098339	717242	93020	810262
56		81104	81104		101379	101379
57		110129	110129		61183	61183
58		121918	121918		29154	29154
59		45794	45794		14311	14311
60	431558	33908	465466	177050	33908	210958
61		16558	16558		16558	16558
Total	2531202	986070	3517272	1490717	638373	2129090
Yearly benefit with barrier	1388182					
Total benefit with barrier (40 years calculation period)	29644727					

3.4. WHO including IHD

In Table 5, we can see the estimates summarized in total benefits for the WHO valuation functions including IHD. Note that we only present the more complex structure (see Section 2.5. above) of different impacts of an increased risk of IHD taken from the valuation of adverse health effects in Swärdh and Genell (2016, Section 2.3). Furthermore, we treat these parts as additive. Also, here in Table 5, we present these parts separately.

The most important observation from Table 5 is that the cost of IHD is very low compared to the cost of sleep disturbance and the cost of annoyance. Thus, adding this part to the total costs is barely influencing the total estimate. Other results, not presented in Tables, show that the estimate of IHD costs when using the DW of 0,405 is even much lower than the IHD costs presented in Table 5, wherefore it is not meaningful to present those estimates.

Still, if we compare this IHD cost with the ASEK cost, which includes a part of IHD cost from 58 dB $L_{Aeq,24}$, this IHD cost is relatively high. However, the rating of the impact function for IHD regarding rail noise is low quality (WHO, 2018), meaning that the ASEK values cannot be recommended to be changed based on the impact function for IHD used in our study. Further studies in the future and a possible higher rating of the impact function may change this though.

Table 5 – Valuation of noise cost with WHO functions per year in SEK and 2018 years prices

$L_{Aeq,24}$ in dB	Yearly cost without Barrier				Yearly cost with Barrier			
	Sleep disturbance	Annoyance	IHD	Total	Sleep disturbance	Annoyance	IHD	Total
50	1137735	-	-	1137735	596425	-	-	596425
51		-	-	-		-	-	-
52		187417	14558	201975		109327	8492	117819
53		120511	16984	137495		77471	10918	88389
54		132301	25476	157777		102061	19653	121714
55	961909	136430	32027	1130366	717242	93020	21837	832099
56		81104	21837	102941		101379	27296	128675
57		110129	32755	142884		61183	18197	79380
58		121918	39063	160981		29154	9341	38495
59		45794	15528	61322		14311	4853	19164
60	431558	33908	12010	477476	177050	33908	12010	222968
61		16558	6066	22624		16558	6066	22624
Total	2531202	986070	216303	3733575	1490717	638373	138662	2267752
Yearly benefit with barrier	1465823							
Total benefit with barrier (40 years calculation period)	31302765							

3.5. WHO with much less night traffic

In Table 6, we can see the noise-cost estimates summarized in total benefits for the different scenarios using the WHO valuation functions except IHD but with the assumption of less night traffic. We assume that L_{night} is now 10 dB lower than $L_{Aeq,24}$.

The results here clearly show the sensitiveness of the L_{night} indicator for the estimated cost of sleep disturbance. Compared to the former results, the cost of sleep disturbance is now decreased with almost 70 percent. Note also that the share of annoyance and sleep disturbance of these estimates coincide even more with the WHO (2018, p.2) estimates, especially in a context with a relatively low level of night traffic, and although the cost of annoyance here is slightly higher than the cost of sleep disturbance.

Table 6 – Valuation of noise cost with WHO functions and assumption of less night traffic per year in SEK and 2018 years prices

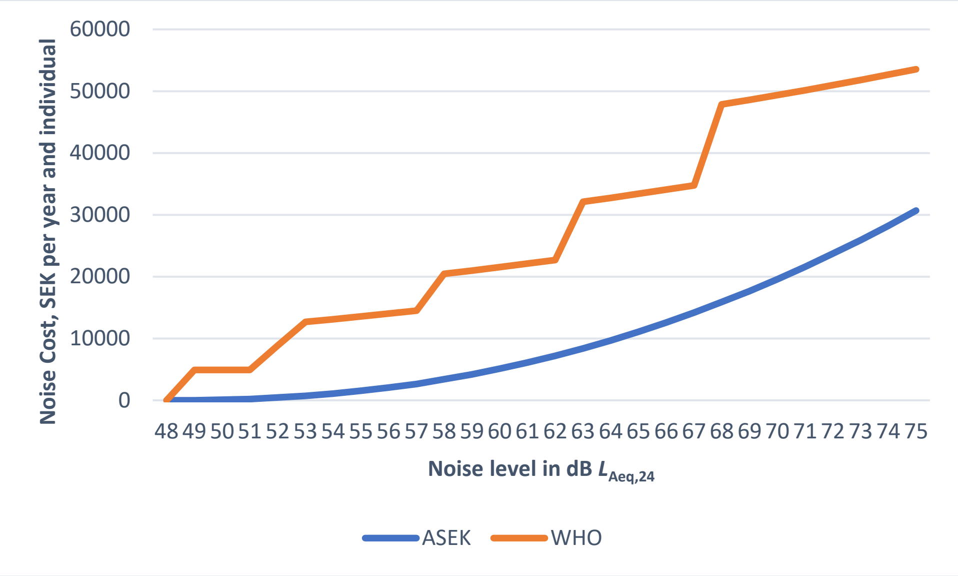
$L_{Aeq,24}$ in dB	**Yearly cost without Barrier**			**Yearly cost with Barrier**		
	Sleep disturbance	**Annoyance**	**Total**	**Sleep disturbance**	**Annoyance**	**Total**
52		187417	187417		109327	109327
53		120511	120511		77471	77471
54		132301	132301		102061	102061
55	564931	136430	701361	421238	93020	514258
56		81104	81104		101379	101379
57		110129	110129		61183	61183
58		121918	121918		29154	29154
59		45794	45794		14311	14311
60	261425	33908	295333	107251	33908	141159
61		16558	16558		16558	16558
Total	826356	986070	1812426	528489	638373	1166862
Yearly benefit with barrier	645564					
Total benefit with barrier (40 years)	13786075					

3.6. Explanation of the differences between ASEK and WHO valuations

Why then are the benefits so different when we apply the ASEK values compared to valuations based on impact functions from WHO (2018)? In Figure 1, the cost of noise exposure per individual and year is presented for different levels of $L_{Aeq,24}$.

We can see from the figure that the ASEK valuation function has a smooth continuous path with no costs below 50 dB and from 50 dB starts to increase up to 75 dB. The valuation based on WHO is discontinuous with a large leap from no cost at 48 dB, followed by a cost that already at 49 dB is almost 5000 SEK.

Figure 1 – Valuation functions of ASEK and WHO (2018) given per individual and year in SEK and 2018 years prices



The reason is that WHO (2018) recommends a level where there are adverse health effects based on the share of disturbed individuals. This limit share is set to 10 percent, which already at the lowest noise level with annoyance cost (52 dB) implies annoyance costs of somewhat 4000 SEK.

Furthermore, we can see that the ASEK-valuation function and the valuation based on WHO (2018) are relatively closer to each other when the noise level is high. As most of the exposure levels in our case study of Ytterby are relatively low (61 dB and lower), this translates into a large difference between benefit estimates based on ASEK and WHO (2018). If the exposure levels would be higher, the relative difference between our valuation methods would be smaller.

3.7. Generic application

We can also apply our model to a more general train commuting suburb, which then require knowledge about the number of exposed individuals at different dB levels in $L_{Aeq,24}$ before and after a given measure, which is not needed to be a noise barrier. This general application is available as an Excel application, supplementary to this paper, and downloadable at https://swopec.hhs.se/vtiwps/abs/vtiwps2019_005.htm

4. Discussion and Conclusions

We have estimated the benefits of a noise barrier in a train commuting suburb in Sweden. The noise benefit is the noise cost without a noise barrier subtracted with the noise cost with a noise barrier.

The purpose of this study was to compare different valuation functions for a noise abatement measure, e.g., a noise barrier, in an exploitive train commuting suburb.

The noise cost is strongly decreased, in these examples with about 40 percent, when the barrier is constructed and thus has the potential to decrease the noise cost substantially. On the other hand, for the noise barrier to be efficient, the noise cost to begin with need to be high, either because of many people living in the train commuting suburb or higher noise levels.

The noise benefits have been estimated using two different approaches, the ASEK method based on official Swedish guidelines (Swedish Transport Administration, 2018) and using impact functions from the recent WHO (2018) recommendations.

Our results show that the estimated noise benefits are much higher with the WHO method than the ASEK method. The benefits of the WHO method are dominated by reduced sleep disturbance followed by reduced annoyance. Importantly, as sleep disturbance are the largest component, the WHO estimates are extremely sensitive to the nightly noise level, L_{night}.

The increased value of property due to noise abatement may be approximately estimated by our model. Given the noise level before and after the measure, all individual benefits are likely to be capitalized into the property market with a reservation for rented apartments and rent control. It would, however, be more difficult to calculate the benefits if the measure is mandatory for the permission to build new dwellings at all, as in this case there is no clear alternative scenario to compare.

In addition, the meaning of developing a train commuting suburb is to increase the population through new housings in locations nearby the railway station. This will, consequently, increase the benefits of a noise-reducing measure as more individuals will benefit from it.

What important discussion is then needed in the light of these results, especially regarding the large difference between estimated ASEK benefits and WHO benefits? Here follows briefly some, by the author, identified discussion points.

First of all, the noise-abatement benefits of ASEK is based on a willingness-to-pay approach derived from differences in the market of single-family houses. In other words, the impact function of ASEK already includes the monetary valuation. The method based on the WHO recommendation, on the other hand, includes a willingness-to-pay component that is more indirect and related to the value of a lost life year, which is willingness-to-pay based at the end of the valuation chain of the impact pathway approach (IPA). Both methods involve uncertainty, but the several steps of the WHO method may involve more uncertainty.

What different effects are included and not included in the monetary valuation of the benefits? The calculations based on WHO is treating the annoyance, sleep disturbance, and IHD (if applicable at all) as additive effects. In the ASEK calculations, on the other hand, the largest part is based on differences in prices of single-family houses (there is also a small part based on increased risk of IHD that is treated as additive). What effects that are capitalized into the housing market is not easy to determine. Annoyance cost is usually thought to be included, but what about sleep disturbances? On the one hand, very few house buyers are likely to visit their prospective house during night-time before the property transaction takes place. It can also be the case that it is difficult for house buyers to observe high noise levels during week-day rush-hours as houses for sale are usually visited during evenings and weekends. On the other hand, buying a single-family house is likely to be, if not the most important, one of the most important investments of a household, which suggest that effects like traffic-noise exposure are treated carefully by housing buyers.

Another consideration is whether the different effects are additive or if an additive treatment implies a risk of double counting. Annoyance and sleep disturbance may, as an example, be highly related to each other and the costs of these adverse health effects might be overlapping.

The different adverse health effects and their inclusion in the value capitalized into the housing market might also change over time. Especially when people's knowledge about adverse health effect, other than annoyance, from noise exposure increase. Also, the noise cost in the ASEK guidelines has been increased based on new research during the last decades, which could suggest a change over time. However, this change may also be a result of, e.g., a change in preferences or a change in the method for estimating the noise cost.

Another important issue, especially regarding valuation based on housing prices, is the selection effect when comparing the current inhabitants in a train commuting suburb with people moving to a developed train commuting suburb. The benefits of noise-exposure measures might be valued lower by new inhabitants, whose choice to move to the developed train commuting suburb might be interpreted as their valuation of increased accessibility is higher than their disutility of high noise exposure. In all, the characteristics and preferences of the residents will probably change when a train commuting suburb is developed.

An important question is whether it is possible to finance the noise-abatement measures via increased land values. Our estimates of the ASEK guidelines based on housing differences show that the benefits of existing people in Ytterby is not even close to the investment cost of the noise barrier. However, a large housing development close to the railway station might be sufficient for financing a noise measure, if the number of newly constructed dwellings are high. Nevertheless, there is also a certain risk to overestimate the benefits as this increased cost might not be able to forward to the housing buyers that are the final consumers in this market.

Other noise measures may result in similar noise abatements and at the same time lead to other benefits. One such example is a multistory carpark located closest to the railway. Such a car park may serve as a noise barrier and more areas are accessible for new housings. A concern about a multistory carpark might be a worsen view for some dwellers. Still, a noise barrier might worsen the view as well.

To summarize our paper into a few conclusions, an important one is that the kind of impact functions and valuation functions that are used have a huge influence on the estimated benefit. This can be viewed as a problem, mostly since the analyst/researcher easily can choose the method to support the hypothesis or the underlying purpose of the estimation. Furthermore, there is a certain risk of skepticism about the monetary valuation of noise abatement as the different methods show these different results. As this paper elaborate these differences, it may help the understanding of the benefit estimates.

Another important conclusion is that there is a need of established impact functions if a guideline should be revised. The risk of double counting is obvious, although we cannot know for certain that all impacts of noise exposure are included. In Swedish guidelines, the noise cost is based on willingness to pay for noise abatement related to what is capitalized into the housing market. Then, Swedish Transport Administration (2018) has assumed that ischemic heart disease is not included but sleep disturbances are. As sleep disturbances are (when there is some night traffic) the largest part of the noise cost in WHO (2018) recommendations, the guidelines in Sweden would be much higher noise costs if the sleep disturbance would be included as an additive part. Before we have some evidence regarding sleep disturbance, the conservative approach is to not include this part in the Swedish guidelines.

Therefore, finally, the most important next step in a Swedish context regarding estimates of noise costs might be to analyze to what extent sleep disturbance is included in the noise cost estimated through differences in noise exposure of Swedish single-family houses.

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