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Costs and benefits of US aviation noise land-use policies

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ABSTRACT

Aircraft noise affects human health and welfare. One method US airports use to mitigate the impact of noise on nearby residents is through sound insulation and residential land acquisition projects. Costs of residential insulation and acquisition projects are taken from federal grant summaries while the benefits of noise reduction are calculated as the combined willingness-to-pay for abatement and direct and indirect costs of illness from hypertension, myocardial infarction, and stroke. We show that the average cost of sound insulation projects is $15,600 per person affected while that of land acquisition is $48,900 per person affected. We find that for only in 15% of projects do the benefits to residents from willingness-to-pay for reduction and reduced risk of mortality and morbidity exceed the costs of sound insulation for residences exposed to 65 dB Day Night Level (DNL) of noise. Our estimates suggest that noise insulation projects are more cost-effective than fleet wide mandatory aircraft retirement.

Introduction

While air transportation contributes significantly to economic growth and employment (Allroggen and Malina, 2014; Button and Yuan, 2013; Percoco, 2010), it also leads to externalities in terms of climate and human health. Of particular concern are noise externalities, since it has been shown that at levels above 55 dB Day Night Level (DNL), a measurement of noise over a 24 h period that weights events during primary sleeping times, noise becomes an increasingly important and detrimental aspect of the environment (EPA, 1974). Noise affects communities through various interlinked pathways causing annoyance, sleep deprivation and interruption, learning disruption, and cardiopulmonary health effects (Goines and Hagler, 2007). Noise pollution also affects the natural environment (Pepper et al., 2003) and can impact the human appreciation and enjoyment thereof (Miller, 1999). Noise from landing and take-off operations can impose a burden on communities as far away as 20 km from a major airport, and overhead operations can have a societal impact in areas with low levels of background noise, such as national parks (Wolfe et al., 2014).

Several policy approaches and methods are available for controlling the impact of aviation noise. Aircraft noise has been regulated globally through aircraft certification standards promulgated by the International Civil Aviation Organization Committee for Aviation Environmental Protection (ICAO CAEP) since 1971. Although there have been increases in stringency of these standards over time, aircraft noise is still the greatest concern for communities living near airports (Durmaz, 2011). Other command-and-control source-based policies include mandatory phase out of noisier aircraft at the national and international level, and per-movement limits set at the airport level (Girvin, 2009). Globally, various governments and airports

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have adopted other noise-abatement policies and procedures including quotas, curfews, direct noise charges, preferential runway treatment, and land-use management. Two land-use management policies that have been adopted at a number of US airports are noise insulation and land acquisition.

Previous research on aviation noise policies has not specifically examined the role of land-use management policies. Janić (1999) and Girvin (2009) present a qualitative assessment and comparison of noise mitigation policies including acquisition and insulation, but do not consider the direct assessment of costs or benefits from these land-use change policies. Other studies have examined the costs and/or benefits of alternative noise policy instruments including mandatory retirement of noisier aircraft (Morrison et al., 1999), airport per-movement and cumulative noise constraints (Brueckner and Girvin, 2008) increase in certification stringency (Wolfe et al., 2014), and noise taxes and fees (Morrell and Lu, 2000; Brueckner and Girvin, 2008). Mahashabde et al. (2011) examine the co-benefits and tradeoffs to noise of an emissions-based policy and its impact on net policy costs and benefits. However, an assessment of land-use policies and their impact on social welfare has not been done. This is the first quantitative assessment of the costs and health and welfare benefits of land-use management noise mitigation, specifically housing insulation and property acquisition, as it has been applied in practice at US airports.

We examine land-use management at 16 US airports. We use the FAA Airport Improvement Program (AIP) Grant Histories to determine the costs of these programs as a function of the number of people impacted. We use a willingness-to-pay for noise abatement formulation based on a meta-study of hedonic pricing surveys to compute the benefits of these improvements from changes in housing values. Utilizing exposure–response relationships from the literature, we also compute the costs of aviation noise-induced hypertension and myocardial infarction. We use these health costs to estimate the bounds of the social welfare benefits of land-use policies. Finally, we assess the costs and benefits of land-use management through traditional policy perspectives such as cost-benefit assessment and cost-effectiveness and compare the results to other policy instruments.

This paper is organized as follows: Section 'Literature review' provides a background on aircraft noise and justification for noise abatement and mitigation policies, Section 'Methodology' describes the data sources and methods used to determine the costs and benefits of acquisition and soundproofing policies, Section 'Results' presents analysis results, and Section 'Discussion' provides a discussion of the policy implications and quantitatively and qualitatively compares land-use management policies to other abatement and mitigation strategies.

Literature review

Aircraft noise as an externality

Commercial air transportation generates numerous direct, indirect, and induced benefits and can be a driver of economic growth (Button and Yuan, 2013; Green, 2007). However, the expansion of the national airspace system and the associated infrastructure has driven the need for assessments of the external costs of aviation. Safety, congestion, local air pollution, water degradation, and climate change are all important and potentially adverse considerations. Aviation noise is one such negative externality that is borne by individuals who may not be the direct producers, users, or beneficiaries of the airspace system. Noise is a byproduct of aircraft operations both enroute and in the airport vicinity as well as of ground support equipment. Furthermore, airport use and development can induce greater noise pollution through an associated increase in ground traffic to and from the airport (Gosling, 1999).

Noise annoyance is used as a broad term to describe a reaction in which individuals, groups, or communities would, if given the possibility, actively try to reduce exposure through mitigation or avoidance (Molino, 1979). Because noise is a subjective experience, translating exposure to a measure of predicted annoyance is non-trivial, and there is a large variation in individual reactions to the same exposure levels (Miedema and Oudshoorn, 2001). He et al. (2014) performed a meta-study of hedonic pricing surveys relating noise exposure to property value loss. They assessed nine different models relating willingness-to-pay for noise avoidance and variables available from 63 noise studies including proximity to airport access, the year the study was performed, and the functional form of the underlying study's regression technique. He et al. (2014) recommend a model that expresses willingness-to-pay as a function of metropolitan area average income level using a weighted least squares regression of predicted property values derived from the underlying hedonic noise studies.

Additionally, noise exposure has been linked to changes in human health, including increased risk of mortality and morbidity. Hansell et al. (2013) found a statistically significant increase in hospital admissions for stroke and coronary heart disease for residents living in areas with higher levels of daytime and nighttime noise. Jarup et al. (2008) and Correia et al. (2013) present large multi-airport studies that link aircraft noise exposure to hypertension and hospital admissions for cardiovascular disease, respectively. While the exact relationship between aircraft noise exposure and physical health impacts is still highly uncertain, a growing body of literature suggests that incidences of health endpoints, particularly cardiovascular impacts, can be expressed through an exposure–response curve (Basner et al., 2013). For stroke, Hansell et al. (2013) find a relative risk of hospital admissions of 1.24 (1.08–1.34) for people living in the highest noise level (>63 dB) compared to the lowest noise levels. For comparison, Floud et al. (2013) finds an odds ratio of 1.25 for every 10 dB for 'heart disease and stroke' based on a study of six EU cities. However Floud et al. (2013) include changes in average night-time noise only and control for people who had been in the same residence for more than 20 years. Nevertheless, they find positive but smaller odds ratios for day-time air traffic noise exposure and air traffic noise exposure not controlled for residence length (1.11 and 1.12 per 10 dB respectively), but these results lack statistical significance at the 0.05 level. Correia et al. (2013) find increased hospital admission rates for all cardiovascular endpoints including cerebrovascular (stroke) events, of 3.5% per 10 dB noise at US airports, but this analysis is limited to the population older than 65. Swinburn et al. (2015) present a review of fifteen studies linking transportation noise and cardiovascular disease and estimate that a 5-dB noise reduction scenario would reduce the prevalence of hypertension by 1.4% and coronary heart disease by 1.8% in the US. The relationship between noise exposure, and in particular aircraft noise, and stroke incidence is still uncertain (Huss et al., 2010; Kolstad et al., 2013).

Valuing aircraft noise damages

It is useful to measure welfare loss in monetary terms so that disparate impacts can be quantitatively compared in common units and so that the benefits and tradeoffs of policy options can be assessed. Previous studies have used depreciation in housing value as a way to monetize the impacts of noise (Wadud, 2009) or through stated preference surveys (Bristow et al., 2014). By investigating the housing market in the vicinity of an airport, one can develop a relationship between the exposure to aircraft noise and observed differences in housing value, while controlling for other determinants of housing value such as neighborhood amenities, community composition, and access to the airport. This relationship can be quantified as a percentage decrease in property value corresponding to a 1 dB increase in time-and frequency-weighted noise exposure. Housing value depreciation can be treated as a proxy for the willingness-to-pay for noise removal since, with compensation equal to the differential between the value of the house under a noise burden and the unaffected house, a person would theoretically be able to move to an equivalent house in a quieter area.

However, housing value may be an incomplete proxy for the overall health and welfare impacts since it likely only accounts for the perception and comprehension of the negative effects from noise and therefore may not reflect the actual risk or burden of long-term health effects (Harrison and Rubinfeld, 1978). The cost of long-term health impacts from environmental noise pollution can be approximated by calculating direct costs of illness, indirect costs, and productivity losses from the increased relative risk of disease. An assessment environmental noise pollution found that reducing U.S.-wide noise exposure by 5 dB would yield $3.9 billion in benefits from reduced incidences of coronary heart disease and hypertension (Swinburn et al., 2015). Furthermore, using housing price differentials implicitly assumes there is a well-functioning and equilibrium housing market and that households can move between equivalent dwellings with minimal transaction costs (Freeman, 1979; Gjestland et al., 2014). A study in the Netherlands found evidence that a more appropriate noise damage function would include a residual cost differential accounting for impacts not accounted for in the housing market (Van Praag and Baarsma, 2005).

Noise policies

US case law, which has placed liability for damages on airport proprietors (Falzone, 1998), has upheld the view that aircraft noise constitutes a taking of property. With property rights assigned and in the presence of minimal transaction costs, bargaining will lead to the most efficient use of resources and the maximum of net social welfare – regardless of the delineation of property rights (Coase, 1960). However, transaction costs can be real and significant. The number of parties impacted by noise near any individual airport can be in the thousands, making the time, effort, and money required to bargain with each party practically infeasible. Bargaining through multi-party agreements also opens up the possibility of classical collective action problems such as free-ridership or holdouts that would eliminate the chances of an efficient outcome. Furthermore, the noise impact is inhomogeneous across different airports and can vary significantly in the vicinity of a single airport. If some people disproportionately bear the costs of aircraft noise, it may represent a social justice concern (Sobotta et al., 2007). Thus, aviation noise presents a strong case where government regulation may be appropriate.

The International Civil Aviation Organization – Committee for Environmental Protection (ICAO-CAEP) promotes a "balanced approach" to mitigating the impact of aviation noise by splitting noise regulations into reduction of noise at the source, operating restrictions, environmentally-appropriate operating procedures, and land-use planning and management (ICAO, 2004). This paper focuses on two land-use planning policy mechanisms: residential noise insulation and residential land acquisition. Other regulatory options are available that address land-use management. An intense form of such a policy is to move the primary airport location or to site a new airport in a remote location or on reclaimed land. For instance, the Osaka Kansai airport was constructed on an artificial island, thereby reducing the need to control near-airport land-use and reducing the possibility of residential noise-sensitive areas (Janić, 1999). More commonly in the United States, airports fund land acquisition or residential sound insulation projects to reduce the burden of aircraft noise on communities (Girvin, 2009). While 55 dB DNL is the EPA recommended noise level requisite to protect for health and safety (EPA, 1974), the FAA has set 65 dB DNL as the threshold for incompatible land use (FAA, 2006). However, the FAA does not require airports to directly assess the monetary benefits of noise insulation and land acquisition projects (FAA, 2009). Nevertheless, from a societal perspective, it is important to evaluate their economic costs and benefits. A comparison of the economic costs of these policies with their direct impacts on societal welfare is the primary contribution of this paper. The use of residential property value loss from hedonic pricing methods and human health costs from exposure–response relationships can provide an indication of the economic reasonableness of US aviation noise land-use properties.

Methodology

Policy costs

Under Part 150 of the Federal Aviation Regulations, participating airports are eligible for noise compatibility grants through AIP grants and moneys from Passenger Facility Charges (PFC). We take data from AIP grant reporting from 2000 to 2012. There are 11 airports for which grant reporting provides both the money provided by AIP and the number of people impacted by the land-use change. For five airports, only the number of households impacted is provided, and we convert the household impact to a per person impact by assuming a US average house of 2.6 people per household. Of these 16 projects, ten implemented noise insulation and soundproofing while six implemented primary land acquisition. Where a project applied for grants over several years, we use the total cost of the project per person.

Noise compatibility projects are eligible for 80% federal share of costs at medium and large hub airports and 90–95% federal share of costs at other airports (FAA, 2009). We assume that the total cost of the airport project reflected full allowable cost sharing from federal funds. Costs for all projects are converted to 2010 dollars using the Consumer Price Index (CPI). Costs per person for the 16 airport noise projects considered are shown in Fig. 1.

The average cost for home insulation across all noise projects considered is $15,600 per person affected, and the average cost for property acquisition across all noise projects considered is $48,900 per person affected (2010 USD). For comparison, a U.S. Government Accountability Office (GAO) analysis of FAA Noise Grant beneficiary goals found that average yearly AIP noise grant expenditures for all noise grants rewarded not broken down by expenditure type or project location ranged from $14,050 to $22,219 per beneficiary, and that 71% of projects occurred at primary commercial airports (GAO, 2012). This is equivalent to average total project costs of $16,600–$26,300 per beneficiary.

Benefits valuation – hedonic pricing meta-study

The benefit of a given land use policy is equal to the monetized damages avoided due to an effective decrease in the noise level borne by a given population. The contribution of aircraft noise to monetized property damages is calculated using the algorithms of the APMT-Impacts Noise Module (He et al., 2014). The willingness to pay per dB of excess noise is given by $WTP = \alpha + \beta \times Income$ where α and β are the probabilistically defined model intercept and coefficient (He et al., 2014) for US only aircraft noise impacts as applied in a US noise analysis in Mahashabde et al. (2011). Income level is taken at the Metropolitan Statistical Level (MSA) for 2010 as provided by the U.S. Bureau of Economic Analysis. An MSA is a census-designated geographic region defined by close economic ties as defined by the Office of Management and Budget. The decibel level benefit is determined as the difference between the noise level with aviation operations and no insulation and the expected noise level after policy implementation. Because property acquisition effectively removes the noise-afflicted population from all aviation noise, the expected noise level after implementation is assumed to be the background ambient noise level. Noise insulation does not fully mitigate the impacts of aircraft noise on property. Even if the insulation were to fully soundproof the residence, the affected persons would still be limited as to when they could open their windows or to how they could enjoy outdoor space on their property. Van Praag and Baarsma (2005) find that the presence of noise insulation

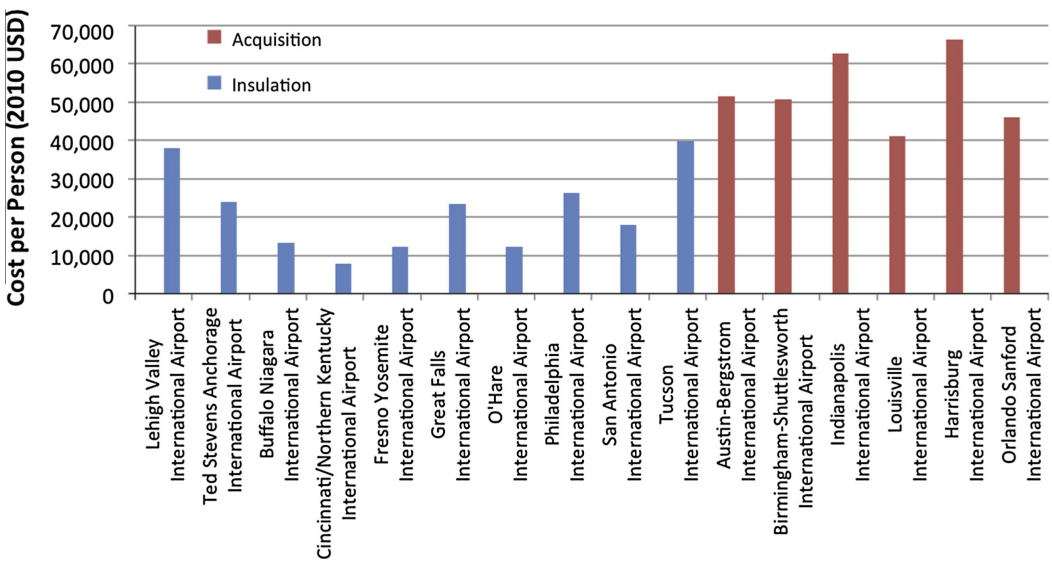

Fig. 1. Airport specific aviation land-use policy cost per person affected.

improves residential welfare by 2/3 the amount of eliminating the noise burden and note similar results from Feitelson et al. (1996). We adopt this assumption for our analysis. We use a uniform distribution for the background noise level of 50–55 dB DNL (Navrud, 2002; Nelson, 2004).

Benefits valuation – health costs

We calculate the costs associated with three health endpoints: hypertension (HYT), myocardial infarction (MI) and stroke.

The relative risk for MI and HYT for each five dB DNL band from a meta-study by Basner et al. (2013) and the baseline incidence rate for those endpoints for U.S. residents aged 20 and over by age and gender (Go et al., 2013) were used to calculate the expected impact incidence rate for each age, dB level, and gender combination. For HYT, there is limited evidence that disease incidence has an effect on expected future earnings so damages are calculated using annual expected medical contact, hospital, and drug costs (Cropper and Krupnick, 1990). The CPI was used to adjust expenditures to a consistent base year of 2010, resulting in annual medical expenses of $776 per HYT incidence. Average life expectancy by age and gender (Arias, 2014) and a discount rate of 3% were used to determine net present value of total noise damages.

For MI, the bulk national fatality rate due to MI (Myerson et al., 2009) was used to separate morbidity and mortality impacts. Mortality impacts were valued using two methods frequently used in policy analysis: a Value of Life (VSL) of $7.93 M (2010 USD) as recommended by the US EPA (EPA, 2006) and a Value of Life Years Lost (VOLY) from Bickel and Friedrich (2005) using Purchasing Price Parity (PPP), CPI, and a 3% discount rate and the over the expected remaining life expectancy (Arias, 2014) to determine net costs in a consistent baseline year. Non-fatal MI costs were calculated as the sum of opportunity costs and direct medical costs by age at a 3% discount rate using the approach and values outlined in the EPA's Regulatory Impact Analysis for the Federal Implementation Plans to Reduce Interstate Transport of Fine Particulate Matter and Ozone in 27 States (2011).

We apply a linear relative risk of 1.24 for every 15 dB of noise over 50 dB DNL consistent with Hansell et al. (2013). We examine the uncertainty of our results to a range of relative risks that span the literature (including a relative risk of 1, indicating no increased risk) as described in Section 'Uncertainty estimation' and note the need for continued research in this area.

For our analysis, the baseline prevalence rate and the one-year mortality rate for all-cause strokes by age and gender are taken from Go et al. (2013). Lifetime stroke costs by age of first onset are taken as the sum of direct (hospitalization and rehabilitation) and indirect ischemic stroke costs from Taylor et al. (1996). In addition to opportunity costs from lost wages due to morbidity and mortality, indirect costs from stroke used here include the nonmarket value of household services.

The total health cost per person at each dB level is taken as the sum of the person-weighted average health costs of MI, HYT, and stroke. The policy benefit from land acquisition is taken as the difference between the expected health cost per person at a given dB level and the expected cost with no aviation-related noise (the background noise level), while the benefit from insulation is taken as 2/3 of the same benefit in accordance with Van Praag and Baarsma (2005) as an approximation.

Combining direct health costs with willingness-to-pay values from hedonic pricing studies may contribute double-counting of those health impacts that residents bear, recognize, and attribute to aviation noise. Not all health costs are borne by the afflicted person, and therefore those costs may not be accounted for by the noise hedonic. Cropper and Krupnick (1990) find that only 23% of total hypertension costs are borne by affected individuals and their families. Furthermore, many residents may not perceive the potential health impacts of noise exposure. Between 2007 and 2008, 20% of hypertensive adults were unaware of their health status let alone had the ability to attribute their disease to genetic or environmental causes (Egan et al., 2010). Eriksson et al. (2010) find that the relative risk of HYT from noise exposure is strongest with those residents who report annoyance to aircraft noise, suggesting that some of the health costs may be captured by the hedonic. Ecoplan (2011) assume willingness-to-pay for abatement accounts primarily for noise annoyance and sleep awakening impacts while health impacts from cardiovascular endpoints can be considered in addition to these willingness-to-pay values. We apply this approach, but note that the possibility for double counting exists, and the actual combined costs of annoyance and health impacts would be bounded by the sum of the health and willingness to pay costs and the willingness-to-pay cost alone.

Uncertainty estimation

We apply Monte Carlo techniques consistent with Mahashabde et al. (2011) to calculate the uncertainty and variability of the welfare benefits associated with noise reductions. To account for the variability of noise land-use policy costs, we fit distributions of sound insulation and land acquisition per person costs to the noise projects considered in Section 'Policy costs'. He et al. (2014) analyze the uncertainty in the willingness-to-pay model (Eq. (1)) in detail. We apply normal distributions on the model coefficients as presented in He et al. (2014). In addition, we use a uniform distribution for the background noise level of 50–55 dB DNL (Navrud, 2002).

For health impacts, we apply a uniform distribution to the relative risk of HYT based on the 5th–95th percentile odds ratios from an aircraft noise meta-study that ranges from no increased risk to an odds ratio of 1.28 (Babisch and Van Kamp, 2009). Babisch and Van Kamp (2009) caveat that the relationship they derive between noise and HYT is only a "best guess", and that more studies are needed to establish a single generalized exposure–response relationship. The impact of the

VSL is examined probabilistically using a Weibull distribution in accordance with EPA recommendations (EPA, 2006) and the VOLY is assumed to be a uniform distribution from 50% to 150% of the mean based on the variation seen in individual studies of the value of a life year (e.g. Lee et al., 2009). The relative risk of stroke is taken as a normal distribution fit to the 5th–95th percentile relative risks from Hansell et al. (2013).

Results

First, we calculate the costs and benefits of the land use policies considering only willingness-to-pay benefits from the He et al. (2014) model based on housing hedonics. Because the willingness-to-pay relationship with noise is a function of MSA income level, results are presented for a range of incomes. Fig. 2(a)–(c) shows the bulk costs of noise land-use policies compared to potential willingness-to-pay benefits for a range of effective dBs avoided for three Metropolitan Statistical Area average per person income levels: $20,000 (a) $40,000 (b), and $60,000 (c). At an income level of $40,000, benefits range from $0 per person at 0 dB removed to $19,000 at 35 dB removed. 5th and 95th percentiles of the noise damages avoided are given by the dashed lines. At 20 dB DNL avoided in areas with average income levels of $40,000 a year or at 16 dB DNL avoided in areas with average income levels of $60,000 a year, the cost of an insulation project is on average covered by the benefits to the residents affected. For income levels up to $40,000, welfare benefits from willingness-to-pay never exceed the cost of even the lowest cost land acquisition projects for the range of dB levels considered.

Fig. 3 shows the policy cost differential considering both health and housing benefits when land use policies are implemented to residences affected by 50 dB DNL through 80 dB DNL in a MSA with an average income level of $40,000. Health impacts shown are calculated using the VSL approach described in Section 'Benefits valuation – health costs'. The typical noise levels at which each land-use policy is implemented are delineated in blue.[1]

At 65 DNL dB, a noise insulation project is expected to cost $7000 per person more than benefits accrued to the affected residents through the combined changes in property value and health impacts. By 75 DNL dB, however, the cost of the housing insulation is equivalent to the welfare benefits to the impacted parties. For land acquisition policies, the welfare benefits accrued by affected parties are valued at $30,000 less than the cost to the airport to purchase that land.

For the 65–80 dB DNL range, health impacts amount to 39–41% of the housing impact using the VOLY approach and 61–64% of the housing impact using the VSL approach as described above depending on the background noise level. For comparison, an EU study found that ischaemic health impacts from noise not including stroke amount to 10% of the willingness to pay costs for the case of road noise (ECOPLAN and INFRAS, 2008) while we find that the health impacts not including stroke account for 14–16% of costs using the VOLY approach.

The results of the uncertainty analysis are shown by the shaded regions in Fig. 3. At the 95th percentile, noise insulation program benefits from willingness-to-pay and health exceed the program costs for all noise levels above 60 dB DNL. However, at the 5th percentile, costs exceed benefits by $28,000 per person even at the noisiest level. The spread in the results is driven primarily by the variability in insulation project costs. The costs of residential land acquisition programs never exceed the benefits to residents measured by willingness-to-pay and health impacts for an income level of $40,000 for the range of dB levels considered. The breakdown of policy costs and environmental benefits are shown in Fig. 4 for three dB and income level combinations. While the average policy costs often outweigh the human health and welfare benefits, they are of the same order of magnitude. Willingness-to-pay for abatement, as related to the noise housing value hedonic, makes of the largest portion of benefits, followed by stroke and MI. The uncertainty in the health impacts relative risks lead to uncertainty ranges in benefits that range from $0 per person (no relative risk) to impacts that approach the magnitude of willingness-to-pay benefits.

Discussion

The results in Section 'Results' show that housing noise-insulation project welfare benefits exceed costs when implemented at noise levels above 75 dB DNL in Metropolitan Statistical Areas with average annual per person income levels of $40,000 or greater. Further, they show that only the 5th percentile of Willingness-to-Pay benefit estimates exceed policy costs of land acquisition at the highest MSA income levels and dB levels when not considering health costs. However, these results should not be interpreted as indicating that these policies are entirely inappropriate at lower income and noise levels. Aviation noise land-use policies provide other ancillary benefits not accounted for in this analysis. Improved airport-community relationships, a reduction of time and resources spent fielding and addressing noise complaints, improved flexibility in airport expansion, and improved flexibility in operational constraints are all additional potential benefits of effective noise land-use policies. Land use acquisition policies in particular have the added benefit that the acquired land may be used by the airport authority or can be rezoned for a more appropriate use given the noise environment. The environmental welfare cost-benefit results here are only one tool in examining policy appropriateness and must be used in appropriate context.

At noise levels of 75 dB DNL and higher, noise is likely to be the most important environmental community impact. When comparing alternate noise policies, it is helpful to consider all of the co-benefits, and the cost-effectiveness of reducing the

[1] For interpretation of color in Fig. 3, the reader is referred to the web version of this article.

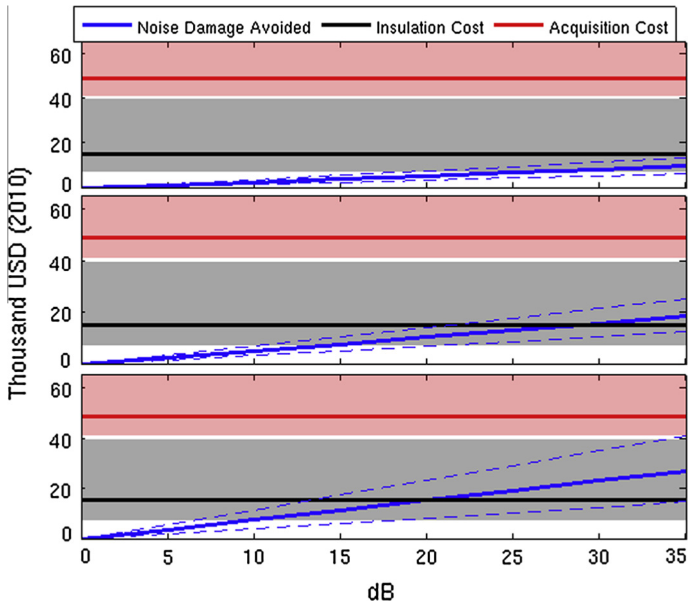

Fig. 2. Per person housing value benefits of noise reduction compared to policy costs at MSA average income levels of $20,000 (a), $40,000 (b), and $60,000 (c) dotted lines represent the 5th–95th percentile ranges of 3000 Monte Carlo runs for the damages avoided. Shaded regions represent the total variability in per person cost across all land-use projects considered.

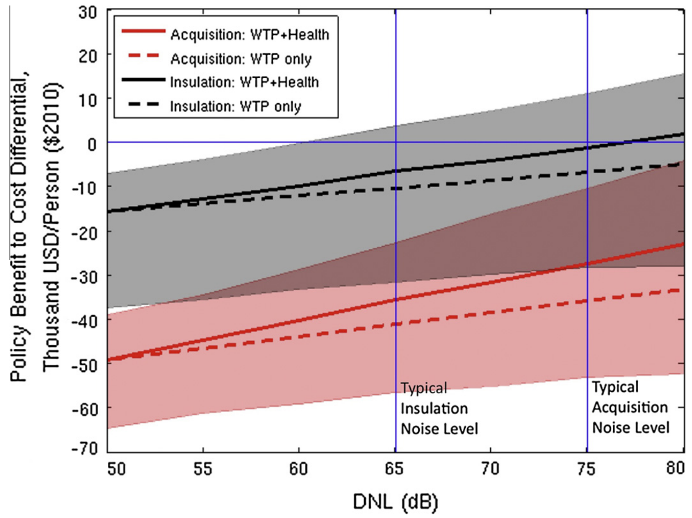

Fig. 3. Policy implementation cost to housing value and housing value plus health value benefit differential for a range of DNL at a city-average income level of $40,000 (2010 $). Shaded regions denote 5th–95th percentile ranges of the uncertainty analysis for combined impacts.

environmental burden of concern. Because land acquisition may be the only way to entirely remove an effected population from the noise burden at high noise levels (>75 dB DNL), it may be the only appropriate policy solution.

Replacing a portion of the fleet with quieter aircraft is another effective strategy for reducing the community noise burden close to an airport. One such strategy for promoting the adoption of quieter aircraft is the forced retirement of aircraft that exceed a certain limit on take-off and landing noise levels. Morrison et al. (1999) investigated the costs of the accelerated mandatory phase out of Stage II aircraft at US airports. They estimate that the phase-out cost is $10B (1995 USD), equivalent to $14.3B (2010 USD), and that the policy resulted in a 5 dB DNL noise reduction for 2,001,000 people previously exposed to >65 dB DNL. By using a valuation of housing prices, which is similar to the technique in this analysis, Morrison et al. (1999) estimate the monetary benefit of this reduction at $4.9B (1995 USD), equivalent to $7B USD (2010 USD). Using the valuation method (Willingness-to-Pay only) described in Section 'Benefits valuation – hedonic pricing meta-study' and assuming an average income level of $40,000, the benefits of the policy would be $5.5B (2010 USD), resulting in a net policy cost of $8.8B (2010 USD). Thus, the policy has a net cost-effectiveness of $880 per person-dB using the

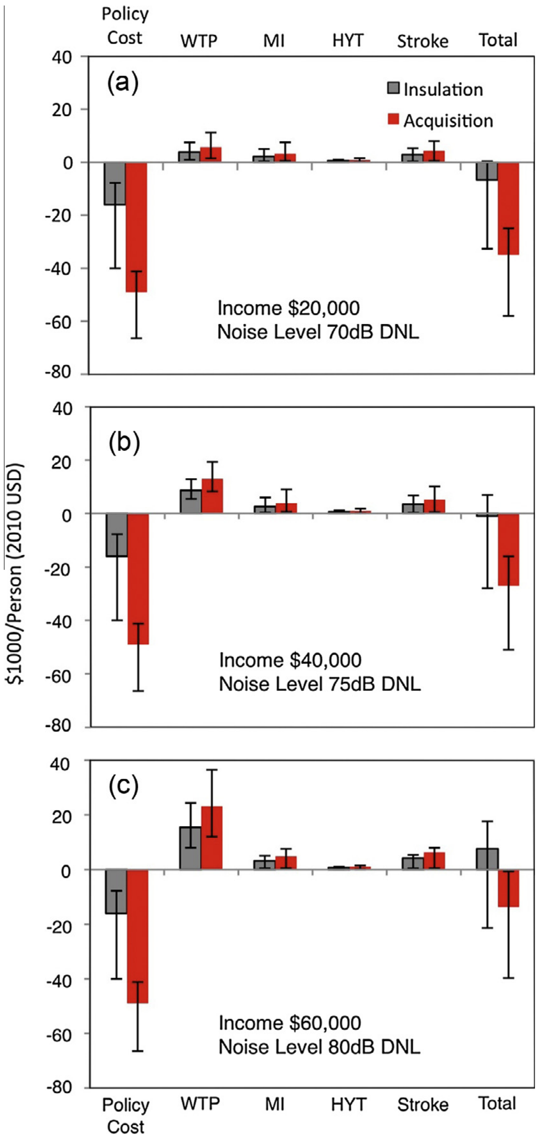

Fig. 4. Breakdown of policy costs and noise benefits (Willingness to Pay [WTP], Myocardial Infarction [MI], Hypertension [HYT] and Stroke) per person in $1000 (2006 USD) for three representative cases: (a) city-level per capita income of $20,000, 70 dB DNL, (b) city-level per capita income of $40,000, 75 dB DNL and (c) city-level per capita income of $60,000, 80 dB DNL.

methodology described above. Alternatively, a noise insulation program at the 65 dB DNL level assuming the same income level has a net average cost-effectiveness of $534 per person-dB.[2] However, accelerating fleet-retirement may have co-benefits to air quality, climate change, and energy efficiency not accounted for in the Morrison et al. (1999) analysis (Lee, 2010; Lu and Morrell, 2006).

Increasing the aircraft noise certification stringency without a mandatory phase-out of older aircraft is another way to accelerate the adoption of quieter aircraft technology. Wolfe and Waitz (forthcoming) examine the costs and benefits of potential policies as part of the International Civil Aviation Organization Committee for Aviation Environmental Protection (ICAO-CAEP) international aircraft noise certification policy process and find that a stringency increase of 5 Effective Perceived Noise in Decibels (EPNdB) results in a net societal benefit of $2.67B (2010 USD) when evaluated at a 3% discount rate, with $0.42B of the benefit coming from environmental co-benefits.

[2] Morrison et al. (1999) estimate that housing insulation costs range from $25,000 to $52,000 (1995 USD) per house based on expert elicitation. This result is equivalent to insulation costs of $13,750–$28,600 (2010 USD) per person. The projects in our study have costs ranging from $7,800 to $39,400 per person with a person-weighted average of $15,600 per person.

Noise taxes and landing fees can be levied to control aviation noise proliferation. Morrell and Lu (2000) provide a detailed summary of how landing fees and taxes are applied at various airports around the world. In theory, noise fees can be charged at a socially optimal rate where the marginal welfare benefit from the induced noise reduction is equal to the cost of the marginal cost of that reduction. Morrison et al. (1999) find that net US welfare benefits from an optimal taxation scheme are small and on the order of $0.28B (2010 USD). Morrison et al. (1999) note that despite this scheme being economically efficient, the relative smallness of the benefit transfer to homeowners may make such a policy politically unattractive.

Conclusions

This study estimates that reducing environmental noise exposure through local land-acquisition and soundproofing policies can provide health and welfare benefits from $10,000 per person when applied in low-income ($20,000 per capita) and low-noise-exposure (65 dB) communities and upwards of $25,000 per person in high-income ($60,000 per capita) and high-noise-exposure (75 dB) communities. However, the costs of these programs often exceed their benefits except for at the highest noise exposure levels. While noise insulation programs do not relieve all the health and welfare damages of aircraft noise exposure, they are more likely to be cost-beneficial than acquisition programs.

This analysis is important for understanding the relative magnitude of health costs from cardio- and cerebrovascular endpoints relative to the more well-understood costs of annoyance from aircraft noise exposure. Together with the work of Swinburn et al. (2015) and Harding et al. (2013), this study provides a first step to estimating the entire costs of environmental noise pollution that accounts for health effects. Further, this study provides an understanding for the economic efficiency of local noise policies as they have been implemented in residential communities over the last decade. This analysis demonstrates that reactionary policies, such as land acquisition and residential soundproofing, are often not cost-beneficial. It therefore suggests that active land-management and zoning are important policy tools to consider in airport planning. The study also demonstrates that there are health and welfare impacts that occur from exposure to noise below the 65 DNL threshold considered to be ‘‘significant noise” by the FAA. These effects may be ignored by analyses that fail to model aircraft noise levels below the 65 DNL threshold. However, the study also suggests that local reactive land-use policies, such as noise insulation projects, are not societally cost beneficial at lower noise levels. As such differentiated threshold metrics, a level at which noise may adversely impact health and welfare and a level at which local policy responses are warranted, may be more appropriate than a single ‘‘significance level.”

More evidence is needed on the cerebrovascular impacts of noise to better constrain the uncertainty in health impacts modeling for policy. Additional differentiated health endpoints, such as stress, mental health, and secondary impacts from hypertension (e.g. dementia) may also be important effects to monetize in future damage estimates.

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