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FUNDAMENTAL FLAWS OF SOCIAL REGULATION: THE CASE OF AIRPLANE NOISE*

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ABSTRACT

This article provides an economic assessment of federal regulatory policy toward airplane noise as encapsulated in the 1990 Airport Noise and Capacity Act (ANCA). This act mandated the elimination of certain aircraft, such as the Boeing 727 and DC-9, from all U.S. airports by the end of 1999 to meet quieter noise requirements. We find that the present discounted benefits of the ANCA, reflected in higher property values for homeowners, fall $5 billion short of the ANCA's cost to airlines, reflected in the reduced economic life of their capital stock. More fundamentally, we find that the net benefits that could have been generated by an economically optimal airplane noise tax amount to only $0.2 billion (present value). It appears that noise regulations have generated substantial costs to society when, in fact, there was little justification on efficiency grounds for regulatory intervention in the first place.

INTRODUCTION

A CLASSIC example of market failure that would appear to justify government intervention is the noise externality created by airplane engines. The intervention Congress took in the early 1970s was to give the Federal Aviation Administration (FAA) regulatory authority to set noise standards for new aircraft designs. In 1977 the FAA established three stages of aircraft noise—for example, the Boeing 707 is a Stage I aircraft, the Boeing 727 and DC-9 are Stage II aircraft, and the Boeing 767 is a Stage III aircraft—and set deadlines to guide the airlines in meeting the (quieter) second-stage noise requirements.[1] As technology progressed, the full elimination of Stage

* We are grateful to Robert Crandall, David Gillen, John Meyer, Don Pickrell, Kenneth Small, a referee, and the editors for helpful comments.

[1] Jon P. Nelson, Economic Analysis of Transportation Noise Abatement (1978); and Ivy Broder, Regulation of Transportation Noise (Occasional Paper, American Enterprise Institute 1987), provide an overview of the 1970s airplane noise regulation.

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II aircraft from all U.S. airports by the end of 1999 was mandated by the 1990 Airport Noise and Capacity Act (ANCA). In contrast to earlier noise regulation that was nonbinding—that is, in pursuit of greater fuel efficiency, most carriers would have replaced Stage I aircraft with Stage II aircraft within the regulatory time frame even in the absence of regulation—roughly 44 percent of carriers' 1990 Stage II aircraft would not have been retired (or retrofitted) by 1999 in absence of the ANCA.[2]

By generating benefits to homeowners who live in areas affected by airplane noise, the ANCA appears to be an appropriate response to market failure. But the ANCA has also generated costs to airlines by reducing the economic life of their capital stock. Surprisingly, analysts have not addressed the basic question of whether the benefits of the ANCA, arguably the most important piece of airplane noise regulation to date, exceed its costs. Our own cost-benefit analysis of the ANCA finds that its $5 billion (present discounted value) in benefits falls considerably short of its $10 billion costs.[3]

More fundamentally, we find that the net benefits that could have been generated by an economically optimal airplane noise tax amount to only $0.2 billion (present value). Just as the ANCA has done, an optimal noise policy would transfer wealth from airlines and travelers to homeowners—although to a much smaller extent. It appears that current FAA noise regulations have generated substantial costs to society when, in fact, there was little justification on efficiency grounds for regulatory intervention in the first place.

The Costs of Noise Regulation

Commercial aircraft have a finite economic and physical life and require replacement at some point. Noise regulations can disrupt carriers' replacement cycles and raise their capital costs if they force carriers to replace a portion of their fleet earlier than planned. The costs of regulations are reflected in the accelerated depreciation of affected aircraft. For example, Figure 1 shows that the value of Stage II aircraft declined nearly 20 percent in the year following the announced phaseout of Stage II aircraft in the fall of 1990. Aircraft values did not adjust immediately to the announced phaseout and continued to decline in subsequent years. It is obviously difficult to in-

[2] Federal Aviation Administration, Report of the Secretary of Transportation to the United States Congress Pursuant to Section 9303 of the Aviation Safety and Capacity Expansion Act of 1990 (1992). Airports do not have the authority to regulate noise without the approval of the FAA. Only a few airports have noise regulations that specify the noise level of planes.

[3] Nelson, *supra* note 1, conducted a benefit-cost analysis of the FAA's earlier airplane noise abatement retrofit program and found that the net benefits of this program were small or possibly negative.

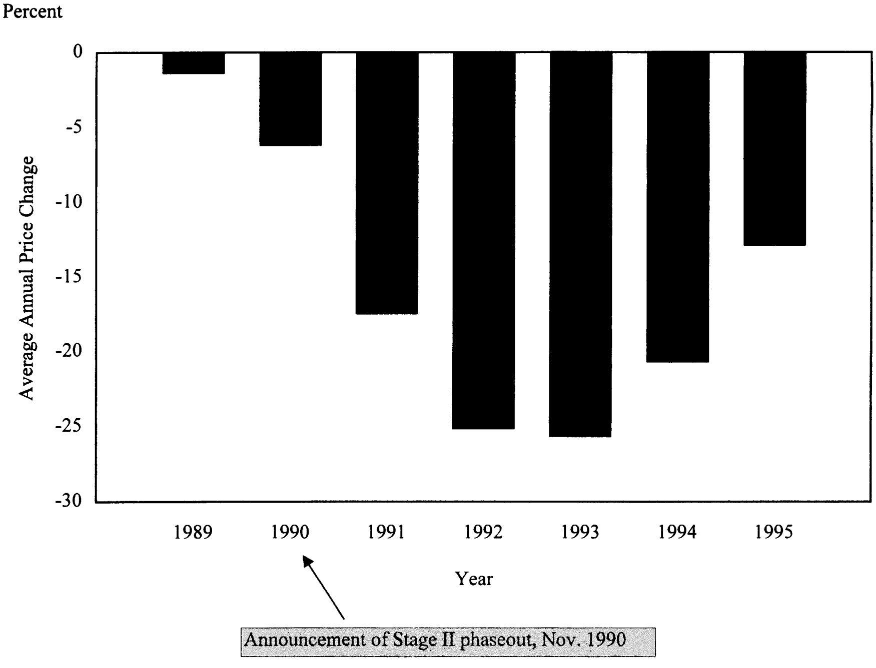

FIGURE 1.—Average real price change from the previous year in Stage II aircraft, 1989–95. Source: Authors' analysis of 1,857 Stage II planes built before 1985, based on Aircraft Appraisal Association aircraft price data.

fer from this figure precisely how much the 1990 Airport Noise and Capacity Act contributed to the depreciation of the industry's Stage II aircraft. We therefore develop a simple life cycle cost model to estimate the costs that are attributable to the ANCA. The model rests on the notion that planes are durable capital goods that have revenue-producing capabilities over time. Airlines incur a cost in every time period to maintain their existing capital stock. The effect of the ANCA is to make a portion of an airline's capital stock obsolete, thus raising an airline's cost of maintaining its desired capital stock.

Carriers can meet the ANCA Stage III requirements by replacing their Stage II aircraft with Stage III aircraft or by retrofitting their Stage II aircraft with "hush kits" so that they comply with Stage III standards. It is reasonable to assume that these costs are comparable because airlines have not revealed a clear preference to retrofit rather than replace. Our analysis will therefore be based on a fleet replacement model.[4]

[4] Carriers' decisions of whether to replace or retrofit their planes depend on whether they have an old or new fleet and how well their current fleet is aligned with the markets they currently serve and the markets they plan to serve. In cases where planes are retrofitted, it is

Assume an airline continuously replaces its initial capital stock K_0 at a rate δ such that $K_t = K_{t-1} = K_0$. In every period, the carrier spends $\delta P_k K_0$ to maintain an existing capital stock, where P_k is the price of a unit of capital. At a discount rate r, the present value of the lifetime cost of capital to the airline *without noise regulation* is

$$\int_0^\infty \delta P_k K_0 e^{-rt}\, dt = \frac{\delta P_k K_0}{r}. \tag{1}$$

How does noise regulation affect a carrier's capital costs? Suppose the regulation is announced in the current period $t = 0$ and states that all planes must meet new standards in a given number of years. Let ζ be the portion of the capital stock that does not meet the standards at the time of the initial announcement, so that $\zeta P_k K_0$ is the initial value of the affected capital stock. Following Dale Jorgenson and Randy Nelson and Michael Caputo, we assume that the capital stock, including aircraft affected by noise regulations, declines at a geometric rate.[5] The depreciation rate under noise regulation is denoted by α.[6]

The value of the initial Stage II capital stock declines over time as Stage II planes are replaced by Stage III planes. At each time t, a portion α of

difficult to obtain precise estimates of the cost of noise regulations because these costs include not only the cost of the hush kit and installing it but also the costs of structural modifications to the aircraft and changes in the aircraft's range, payload, and fuel consumption due to the increased weight of the plane. In addition, the costs include profits lost for the time the aircraft is out of service. We will provide a rough estimate of these costs to provide a check on our estimate of the cost of noise regulations based on fleet replacement.

[5] Dale W. Jorgenson, Capital as a Factor of Production, in Technology and Capital Formation (Dale W. Jorgenson & Ralph Landau eds. 1989); Randy A. Nelson & Michael R. Caputo, Price Changes, Maintenance and the Rate of Depreciation, 79 Rev. Econ. & Stat. 422 (1997). The ANCA mandates a schedule for the transition to Stage III planes. Carriers can comply by phasing out Stage II airplanes relative to the number of those aircraft in their fleet on any day between January 1, 1990, and July 1, 1991, or by attaining a given fleet composition by phasing in Stage III airplanes. Under the phaseout option, carriers must reduce the number of Stage II aircraft by 25 percent by the end of 1994, 50 percent by the end of 1996, 75 percent by the end of 1998, and 100 percent by the end of 1999. The fleet composition option requires that 55 percent of a carrier's fleet consist of Stage III planes by the end of 1994, 65 percent by the end of 1996, 75 percent by the end of 1998, and 100 percent by the end of 1999. There are modified regulations for new entrants, and extensions to the deadline may be granted in rare cases. These requirements are based on the number of planes rather than the value of the capital stock, which makes direct comparison to economic depreciation rates difficult. It is clear, however, that carriers are gradually converting their fleets to meet interim fleet mix or phaseout standards, and that Stage II planes are fully eliminated from the active fleet by the end of 1999. We thus use the continuous geometric depreciation rate, accepting Nelson and Caputo's argument that a geometric rate serves as a reasonable approximation of the economic decline of most capital equipment and aircraft in particular.

[6] Note α will depend on how long carriers are given to adapt to the new regulation. A shorter transition time will raise α; a longer transition time will lower α.

the remaining Stage II capital stock is replaced. Thus, at a continuous rate of decline α, an amount $\zeta P_k K_0 e^{-\alpha t}$ remains invested in Stage II aircraft in each time t. Note there is also a loss in each time t in the value of the Stage II capital stock of an amount $\alpha\zeta P_k K_0 e^{-\alpha t}$.

As carriers replace their Stage II fleet with Stage III planes, the value of the Stage III capital stock grows from its initial value of $(1 - \zeta)P_k K_0$. Because the value of the total fleet remains constant, each loss in Stage II value must be offset by a comparable gain in Stage III value.[7] Thus, the value of the Stage III capital stock in each time t that has replaced Stage II stock is $P_k K_0 - \zeta P_k K_0 e^{-\alpha t} = (1 - \zeta e^{-\alpha t})P_k K_0$.

The cost to a carrier of maintaining its fleet under noise regulation may therefore be quite different than it would be in an unregulated environment. Assuming the depreciation rate δ without noise regulation applies to the Stage III capital stock and the depreciation rate α with noise regulation applies to the Stage II capital stock, the capital cost to a carrier in time t is

$$\alpha(\zeta e^{-\alpha t})P_k K_0 + \delta(1 - \zeta e^{-\alpha t})P_k K_0 = (\delta + \zeta(\alpha - \delta)e^{-\alpha t})P_k K_0,$$

and the present discounted lifetime capital costs to the carrier under regulation are

$$\int_0^\infty (\delta + \zeta(\alpha - \delta)e^{-\alpha t})P_k K_0 e^{-rt}\, dt = \left[\frac{\delta}{r} + \frac{\zeta(\alpha - \delta)}{r + \alpha}\right] P_k K_0. \qquad (2)$$

Thus, the increase in the present value of carriers' capital costs due to noise regulation is simply the difference between their costs with regulation (equation (2)) and without regulation (equation (1)):

$$\left[\frac{\delta}{r} + \frac{\zeta(\alpha - \delta)}{r + \alpha}\right] P_k K_0 - \frac{\delta P_k K_0}{r} = \frac{(\alpha - \delta)\zeta P_k K_0}{r + \alpha}, \qquad (3)$$

which amounts to the difference between the regulated and unregulated depreciation rates, α and δ, times the capital stock $\zeta P_k K_0$ that is initially held in Stage II planes, adjusted by a factor $r + \alpha$ to account for discounting and the declining value of the remaining Stage II capital stock over time. This measure does not account for the fact that Stage III aircraft have greater operating efficiency than Stage II aircraft. But because most carriers would not voluntarily adopt Stage III aircraft at the pace mandated by the

[7] Although our analysis assumes carriers seek to maintain an existing capital stock, the findings are not sensitive to exogenous fleet growth. If carriers are growing during the transition, they may find the costs of the regulation easier to absorb because they represent a smaller fraction of their total costs. Nonetheless, the 100 percent depreciation of carriers' Stage II fleets in the year 2000 represents the same absolute loss to carriers regardless of their growth during the transition period.

ANCA, Stage III planes' higher purchase prices exceed the value that most carriers place on their greater operating efficiency.

Parameters and Findings

Our data set includes 56 scheduled passenger airlines that at one time during 1977–95 were operating as a major carrier (annual revenue greater than $1 billion) or a national carrier (annual revenue between $100 million and $1 billion). Data for each carrier's fleet were obtained from Back Information Services.[8] The data include the number of aircraft of each type, as of December 31 for each year, and their year of manufacture. The estimated market value of each of these aircraft for each year was obtained from the Aircraft Appraisal Association of America.[9] We use these data to provide empirical estimates of the parameters that determine the cost of the ANCA to the airline industry.

Portion of the Capital Stock Held in Stage II Aircraft in 1990

On the basis of our data set, we calculate that Stage II aircraft represented 24 percent of the value of the capital stock of U.S. major and national carriers in 1990.[10] Because our data set includes only major and national scheduled passenger carriers, it may not accurately reflect the portion of the capital stock held in Stage II planes for the entire industry, which includes regional carriers, charters, and cargo carriers. The FAA estimates that 55 percent of the planes in the entire industry fleet were Stage II in 1990, which could represent up to 29 percent of the value of the capital stock, according to our estimates.[11] Thus, we use the midpoint 26.5 percent as our base case estimate, and 24–29 percent as a range for sensitivity purposes.

[8] Back Information Services (BIS) is the information services arm of Back Associates, the leading provider of data to the aviation and aerospace industries. Their database covers 40 years and includes airline schedules, fleet profiles, and operational and financial statistics.

[9] Aircraft Appraisal Association of America is a firm that specializes in estimating the value of commercial planes. Estimates based on market transactions were obtained for all aircraft types and vintages in our sample.

[10] The use of 1990 capital stock figures is appropriate because the ANCA was announced toward the end of 1990 and the aircraft market probably did not respond until 1991. If the aircraft market did respond earlier, our cost estimates would be downward biased because less stock would be affected by the ANCA. Stage II aircraft represent 46 percent of the planes in our data set, but only 24 percent of the fleet value, because they are older and less valuable, on average, than Stage III planes.

[11] Federal Aviation Administration, 1995 Progress Report on the Transition to Quieter Airplanes (1995). Stage II aircraft represented 46 percent of major and national carriers' planes and 24 percent of their fleet value. By maintaining this proportion, we estimate that if Stage II aircraft represented 55 percent of the entire industry's planes, they could account for 29 percent of the industry's fleet value.

Total Value of the Airplane Capital Stock

According to our data set, the value of airplanes held by the 30 major and national carriers operating in 1990 was $75.3 billion (1995 dollars). These carriers account for a large fraction, but not all, of the industry's airplane capital stock. We thus compared the entire industry's available ton-miles with the available ton-miles accounted for by the major and national carriers in our sample.[12] This comparison calls for the value of airplanes in our sample to be increased 15 percent, which yields an estimate for the entire industry of $86.6 billion (1995 dollars). This figure may represent an upper bound to the extent that major and national carriers' capital stock is more valuable than other carriers' capital stock. A reasonable lower-bound estimate would call for the value of airplanes in our sample to be increased 10 percent, which yields an estimate for the entire industry of $82.8 billion. We use the average of these two estimates for our base case, $84.7 billion, and the endpoints for sensitivity analysis.

Interest Rate

Because we are analyzing the welfare effects of a public policy, the interest rate should reflect the real social discount rate, which is equal to the real social opportunity cost of capital. This can be separated into the risk-free cost of capital and the risk premium. Although real long-run rates of return on Treasury bonds have averaged close to 3 percent, real long-run pretax rates of return on equities are much higher. We thus use an interest rate of 7 percent in our base case, which is consistent with the social discount rate that the Office of Management and Budget uses in its assessments, and use a range of 6–8 percent for sensitivity purposes.

Depreciation Rate of Planes Affected by Regulation

According to our data set, from 1991 to 1995, the average annual real depreciation rate for Stage II planes was 22.0 percent.[13] At this rate, the vast majority of the fleet will consist of Stage III planes at the end of the transition period. The Stage II planes left at the end of 1999 will have roughly

[12] The industry's available ton-miles were obtained from the U.S. Department of Transportation Form 41 data. These data are available from Data Base Products, a reseller of data filed by carriers with the U.S. Department of Transportation.

[13] This was calculated by averaging the depreciation rates for those aircraft that were represented in the data set in successive years. The price for Stage II aircraft is likely to be significantly affected by noise regulations because U.S. airlines own a large portion of the world's Stage II planes.

3.5 percent of the value of the initial total fleet.[14] Thus, our base case assumption of the depreciation rate of planes affected by regulation is 22 percent, and we consider a range of 20–24 percent for sensitivity purposes.

Depreciation Rate of Planes Unaffected by Regulation

According to our data set, from 1978 to 1990, Stage II planes depreciated at about the same real annual rate, 4.6 percent, as Stage III planes.[15] From 1990 to 1995, a period of relatively slow growth in air travel, Stage III planes depreciated at a real annual rate of 10.4 percent. It is reasonable to assume that Stage II planes would have depreciated at the same rate as Stage III planes in the absence of regulation.[16] If the depreciation rates since 1995 immediately returned to their historical level of 4.6 percent, the average depreciation rate over the entire transition period would be 7.9 percent. This can be interpreted as a lower bound. Because it is very unlikely that depreciation rates have increased in recent years as growth in air travel has accelerated, a reasonable upper bound is 10.4 percent. We use the midpoint of these two values, 9.1 percent, as our base case and use the endpoints for sensitivity purposes.[17]

Findings

Table 1 presents estimates of the costs of the ANCA based on our assumed values of the parameters in equation (3). (In the Appendix, we show that the estimates are comparable to those based on the cost of retrofitting planes with hush kits, and that they are not affected by our assumptions that the capital stock declines at a geometric rate and that output is fixed.) We find that the present discounted cost of this noise regulation amounts to $10 billion (1995 dollars) in the base case. Considering the full range of parameter values yields an upper-bound estimate of $13.5 billion and a lower-

[14] Based on our model, this figure is obtained by calculating the value of Stage II planes remaining after time t, $\zeta P_k K_0 e^{-\alpha t}$. We use the transition time between the November 1990 announcement and the end of 1999, 9.167 years.

[15] This was calculated as explained in note 13 *supra*.

[16] Noise regulations could lower the depreciation rates of Stage III aircraft even though they were not directly affected by the regulations. But it is doubtful that noise regulations created scarcity value for Stage III aircraft because carriers had several years to respond to the regulations with options such as retrofitting. In addition, the fact that Stage III depreciation rates are substantially higher in the 1990s than they were previously suggests that it is unlikely that they were significantly lowered by the ANCA.

[17] Our base case estimate is close to the FAA's finding, *supra* note 2, that a depreciation rate of 8.9 percent would have existed for Stage II aircraft in the absence of regulation. Because the FAA estimate is derived from fleet sizes, it is not fully compatible with our estimate based on fleet values.

TABLE 1

PARAMETER VALUES AND COST ESTIMATES OF THE ANCA

PARAMETER	SYMBOL	BASE CASE	PARAMETER VALUES THAT YIELD	
			Upper Bound	Lower Bound
Portion of initial value of capital stock held in Stage II planes (percent)	ζ	26.5	29.0	24.0
Implied depreciation rate of Stage II planes (percent)	α	22.0	24.0	20.0
Value of airlines' initial capital stock (billions of 1995 dollars)	$P_k K_0$	84.7	86.6	82.8
Interest rate (percent)	r	7.0	6.0	8.0
Unregulated depreciation rate of Stage II planes (percent)	δ	9.1	7.9	10.4
Present discounted cost (billions of 1995 dollars)		10.0	13.5	6.8
Present discounted cost as a percent of initial value of Stage II capital		44	54	34
Present discounted cost as a percent of initial value of total capital		12	16	8

bound estimate of $6.8 billion. To be sure, the airline industry will raise fares in accordance with the supply-and-demand elasticities for air travel to recoup some of these losses from air travelers.[18] Nonetheless, given that the capital losses represent 34–54 percent of the initial (1990) value of the airline industry's Stage II aircraft, and 8–16 percent of the industry's entire aircraft capital stock, the costs of the ANCA appear to be substantial.[19]

The Benefits of Noise Regulation

Because noise regulations make the residential environment surrounding airports quieter, their benefits are reflected in higher housing values. We obtain an estimate of the national benefits of the 1990 Airport Noise and Capacity Act by first determining the extent to which it has reduced noise and the value that noise reduction adds to affected homes. We then estimate how many U.S. households benefit from a more valuable home because of this legislation.

Noise is measured in decibels (dB), which are defined on a logarithmic scale.[20] An increase of 10 dB corresponds to a 1,000 percent increase in sound intensity and a roughly 200 percent growth in the sensation of loudness. Weighting scales, such as the A-scale (dBA), are frequently used to reflect the greater sensitivity of the human ear to certain frequencies.

The effective perceived noise level (EPNdB) is a measure of noise caused by one aircraft event (takeoff, overhead flight, or landing) and considers the sound pressure, duration, and tone of the event at a given location. The Stage I, II, and III classifications for aircraft are based on measures of the EPNdB from the ground for the takeoff, sideline (flyover at 450-meter distance), and approach of different types of planes. A Stage II plane cannot exceed a maximum EPNdB of 102–108 dBA for approach (the greatest noise is allowed for the heaviest planes). To meet Stage III requirements, planes on their approach cannot exceed 98–105 dBA. Similar requirements are imposed for takeoff and sideline noise.[21]

Because the noise level at a given location varies during the day, a cumulative measure of the noise level must be determined. In North America,

[18] Noise regulations will increase capital costs (and marginal costs) in the long run. The costs of the ANCA will therefore include a loss in consumer surplus and, as shown below, a deadweight loss.

[19] We have not accounted for the fact that the increased costs of acquiring Stage III aircraft exceed the value that most airlines place on their greater operating efficiency. This causes a downward bias in our estimate of the costs of the ANCA.

[20] The techniques for evaluating noise levels are discussed at length in Nelson, *supra* note 1.

[21] Federal Aviation Administration, Noise Levels for U.S. Certificated and Foreign Aircraft (1992).

the most frequently used airport noise index is the day-night sound level (DNL), which aggregates the EPNdBs of overhead flights during a day at a given location, weighting nighttime flights very heavily.[22] Typical ambient noise levels in a residential neighborhood unaffected by airport noise are 44–55 dBA. Our analysis considers neighborhoods that experience noise levels above 65 dBA, which are characterized by the FAA as significantly affected by noise. The FAA reports that there are minimal measurable benefits from noise reductions that occur in areas with noise levels below 65 dBA.[23] According to the FAA, maximum noise levels for Stage III airplanes are 2–4 dBA lower than for Stage II planes for takeoff, 5–8 dBA lower for sideline (flyover at 450 meters), and 3–4 dBA lower for approach.[24] These figures indicate that conversion to a Stage III fleet reduces noise in affected areas by 4–5 dBA. We thus construct our benefits estimate assuming that the transition to Stage III planes as required by the ANCA will lower the noise levels of affected homes by roughly 5 dBA (for example, homes in the year 2000 that would have been exposed to 70 dBA in the absence of regulation will instead be exposed to 65 dBA). We then subject this assumption to sensitivity analysis.

What is the monetary value of this noise reduction? As noted by Kenneth Small, the relationship between an externality and property values should be based on estimates of homeowners' willingness to pay.[25] Recently, Youdi Schipper, Peter Nijkamp, and Piet Rietveld compiled 30 estimates of the effect of airport noise on the present value of detached houses and found that the median estimate was 0.61 percent per decibel.[26] Because these estimates do not account for the effects of noise on the value of recreational areas, businesses, and vacant land, we will use a value of 1 percent per decibel as an upper-bound estimate (that is, a 1-dB reduction in the

[22] Federal Aviation Administration, *supra* note 2.

[23] Federal Aviation Administration, Airport Environmental Handbook (1985).

[24] Federal Aviation Administration, *supra* note 21.

[25] Kenneth A Small, Air Pollution and Property Values: Further Comment, 57 Rev. Econ. & Stat. 105 (1975).

[26] Youdi Schipper, Peter Nijkamp, & Piet Rietveld, Why Do Aircraft Noise Value Estimates Differ? A Meta-Analysis, 4 J. Air Transp. Mgmt. 117 (1998). Among the most prominent studies of the value of airport noise reduction in the United States, which control for the accessibility benefits of living near an airport, are Jon P. Nelson, Airports and Property Values: A Survey of Recent Evidence, 14 J. Transp. Econ. & Policy 37 (1980); and Patricia Habuda O'Byrne, Jon P. Nelson, & Joseph J. Seneca, Housing Values, Census Estimates, Disequilibrium, and the Environmental Cost of Airport Noise: A Case Study of Atlanta, 12 J. Envtl. Econ. & Mgmt. 169 (1985). Studies for Canadian homes are by Terrence J. Levesque, Modeling the Effects of Airport Noise on Residential Housing Markets: A Case Study of Winnipeg International Airport, 28 J. Transp. Econ. & Policy 199 (1994); and Dean Uyeno, Stanley W. Hamilton, & Andrew J. G. Biggs, Density of Residential Land Use and the Impact of Airport Noise, 27 J. Transp. Econ. & Policy 3 (1993).

noise level raises the present value of affected *homes* by 1 percent). Given that the ANCA reduces airplane noise by 5 dBA, we assume that its benefits amount to 5 percent of the present value of affected homes.[27]

We estimate the present value of affected homes from noise exposure maps for 35 major airports, which account for roughly 60 percent of airline operations.[28] We assume that the number of houses within the 65-dBA noise contour in 1990, which the FAA defines as significant noise exposure, is a reasonable approximation of the number of houses in the year 2000 that would have been within that contour in the absence of regulation.[29] The housing units affected by airport noise are typically less than 2 percent of the total number of units within a metropolitan statistical area, so it is reasonable to assume that homeowners can substitute between property affected and not affected by noise. The exposure maps are matched with tract-level 1990 census data on median home values, under the assumption that houses are distributed evenly throughout the census tract.[30] This assumption implies that our benefit estimates are biased upward if houses tend to be built in a quieter part of a census tract. For each airport, we calculate the weighted average of median housing values for census tracts that lie wholly or partially within the 65-dBA noise contour.[31] We accept long-standing arguments that current housing prices reflect present values because they incorporate the market's forecast of future developments that might affect these prices.

In Table 2, we summarize the benefits of the ANCA and their components for each airport in our sample and find that the present value of benefits for the country amounts to roughly $5 billion (1995 dollars).[32] The

[27] Following a practice that is standard in the literature, we assume that the benefits of noise reduction are a constant percentage of the value of affected homes. This is reasonable because we are evaluating the effect of changes in noise levels over a fairly small range.

[28] Noise exposure maps are from Noise Compatibility Planning Studies submitted to the FAA by airports participating in the Federal Aviation Regulations (FAR) Part 150 Airport Noise Compatibility Program. Part 150 of the FAR maintains guidelines for the standardization of submitted maps.

[29] If airport traffic increases during the transition period, then the number of houses within the 65-dBA contour is likely to grow because there are more noisy events. But an offsetting effect is that airlines would be gradually making a transition to quieter Stage III planes even in the absence of regulation.

[30] Census tracts were identified using official 1990 census maps from the U.S. Census Bureau. Median house values were based on 1990 census data, provided by the U.S. Census Bureau.

[31] In keeping with intergovernmental standards, FAR Part 150 guidelines consider areas with noise levels of 65 dBA or higher to be affected by noise and do not require noise exposure maps to indicate noise contours below 65 dBA (FAA, *supra* note 23).

[32] The national estimate is obtained by assuming that the proportion of airline operations in the country represented by our sample, 60 percent, is equal to the proportion of the value of the affected housing stock in the country represented by our sample. We adjust this esti-

ANCA affects the value of roughly $100 billion of the nation's housing stock and provides some 800,000 households with an average benefit of more than $6,000. But although the $5 billion in benefits are sizable and widespread, they fall far short of the ANCA's $10 billion costs, resulting in a cost-benefit ratio of 2:1 and casting considerable doubt on the social desirability of this policy.[33]

An Efficient Solution

No one doubts that airplane noise imposes social costs. Our assessment, however, indicates that the Federal Aviation Administration's approach to correcting this market failure has done more economic harm than good. But beyond accurately measuring the costs and benefits of a particular regulation, it is also important to consider whether other approaches to addressing an acknowledged problem could generate significant economic benefits. One solution in this case, for example, might be to allow air carriers to make unconstrained aircraft replacement decisions, but to charge them for the cost of soundproofing houses that are affected by noise. This approach, however, does not appear to be promising because the estimated costs of soundproofing, $25,000–$52,000 per house, significantly exceed the roughly $6,000 in benefits per house from reducing airplane noise below significant levels.[34]

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mate to account for the fact that the average value of a home located near nonsample airports has roughly 81 percent of the value of a home located near our sample airports. The difference in home values arises because major airports, and thus homes in the sample, tend to be located in the largest (and most expensive) metropolitan areas in the country. The adjustment is based on a comparison of the average house price for the "place" where the 35 sample airports are located, with the average house price for the "place" where 165 nonsample airports are located. These 200 airports account for nearly all U.S. airline operations. A place is defined by the 1990 census as a population center, usually consisting of at least 1,000 people and identifiable by name. A metropolitan statistical area (MSA) consists of at least one place (often many), usually with a population of at least 50,000. We used the census-defined place for our analysis because it is typically a smaller unit than an MSA and offers a more accurate picture of housing values immediately surrounding the airport. Nonetheless, our estimate was not perceptibly affected when the average house prices were based on MSAs instead of places.

[33] If, for purposes of sensitivity, we assume as an upper bound that the ANCA reduces the noise levels of affected homes by 6 dBA instead of 5 dBA, then benefits fall $4 billion short of our best estimate of costs and nearly $1 billion short of our lower-bound estimate.

[34] The cost estimates of soundproofing are based on figures supplied by John Driscoll, executive director of the Los Angeles Airport, and from an unpublished/untitled study commissioned to analyze airplane noise at Chicago O'Hare airport. Our conclusion is consistent with David Gillen, Assessing the Efficiency of Noise Insulation Programs (paper presented at the Noise Management Strategy Symposium, San Diego, February 1997), who finds that the costs of soundproofing homes in Denver, Seattle, and Manchester greatly exceed their benefits.

TABLE 2

ESTIMATED BENEFITS OF THE 1990 AIRPORT NOISE AND CAPACITY ACT (1995 Dollars)

Airport Code	Name	Number of Homes >65 dBA	Weighted Average House Price (Thousands)	Total Value of Homes >65 dBA (Millions)	Benefit (5% of Total Value, Millions)	Population >65 dBA (Thousands)	Percent of Total Carrier Operations
LGA	LaGuardia	71,042	179	12,715	636	210	2.00
ORD	Chicago O'Hare International	70,818	161	11,368	568	180	5.44
SAN	San Diego International	21,282	262	5,580	279	53	1.08
DCA	Washington National	16,034	316	5,065	253	34	1.45
JFK	John F. Kennedy International	19,368	204	3,954	198	54	1.66
MIA	Miami International Airport	46,069	84	3,869	193	122	2.46
LAS	Las Vegas McCarran International	20,069	111	2,225	111	38	1.63
MDW	Chicago Midway	23,135	94	2,184	109	59	.59
SEA	Seattle-Tacoma International	14,331	116	1,657	83	33	1.57
DFW	Dallas–Fort Worth International	15,446	104	1,610	81	29	4.70
MSP	Minneapolis–St. Paul International	14,205	102	1,444	72	33	2.07
ATL	Hartsfield Atlanta International	17,107	83	1,428	71	38	3.76
STL	Lambert–St. Louis International	19,634	66	1,286	64	46	2.21
SFO	San Francisco International	4,493	281	1,262	63	11	2.28
MEM	Memphis International	19,959	62	1,241	62	52	1.37

PHX	Phoenix Sky Harbor International	11,125	72	800	40	27	2.33
SJC	San Jose International	3,577	219	782	39	11	.71
TPA	Tampa International	8,524	83	705	35	21	.94
DTW	Detroit Metropolitan Wayne County	10,596	61	646	32	29	2.36
ONT	Ontario International	3,822	139	531	27	13	.71
HNL	Honolulu International	2,610	197	515	26	11	1.49
MSY	New Orleans International	6,354	78	498	25	17	.73
CLT	Charlotte/Douglas International	6,730	71	478	24	17	1.93
BWI	Baltimore-Washington International	3,333	133	443	22	9	.96
IND	Indianapolis International Airport	7,116	58	411	21	18	.89
PIT	Greater Pittsburgh International	2,689	90	243	12	6	2.08
IAD	Washington Dulles International	946	238	225	11	3	.70
PDX	Portland International	1,768	117	207	10	3	.74
MCO	Orlando International	1,904	86	164	8	5	1.62
OAK	Metropolitan Oakland International	450	340	153	8	1	.97
FLL	Ft. Lauderdale Executive	1,304	90	117	6	2	.68
CVG	Cincinatti/Northern Kentucky International	989	87	86	4	3	1.20
SNA	John Wayne (Santa Ana) Airport	250	338	84	4	1	.52
DEN	Denver International Airport	769	99	76	4	2	2.78
MCI	Kansas City International	630	92	58	3	1	.93
Total benefit for 35 airports		468,478	137	64,110	3,205	1,192	59.58
Estimate of national benefit		786,340		99,425	4,971	2,001	100.00

One economically efficient regulatory solution—the approach that would maximize social net benefits—is to set a Pigouvian noise tax that eliminates the gap between the private and social marginal costs of airplane flights. The tax is thus the marginal cost incurred by homeowners from an additional flight. To estimate this tax and its welfare effects, it is reasonable to assume that the typical flight contributes about 0.02 dBA to the daily day-night noise level and about 0.000055 dBA to the annual day-night noise level.[35] Because every flight constitutes two events (one departure and one arrival), each flight contributes 0.000055 dBA to the annual noise levels of affected houses near two airports. Recall that we assume that an additional dBA reduces home values 1 percent. Thus, to construct a noise tax for each of 200 airports (including the 35 original airports in our sample and 165 others), we assume that each additional annual flight (forever) depreciates the value of affected homes surrounding two airports by 0.000055 percent, which is equivalent to depreciating affected homes surrounding one airport by 0.00011 percent. Assuming a discount rate of 7 percent yields an annualized depreciation of 0.0000077 percent. We find that the average amount (weighted by the number of operations at each airport) by which the marginal social cost of a flight exceeds the $13,145 marginal (equals average) private cost of a flight reported in the Appendix is $127, for an average markup of 1.0 percent.

The net welfare gain to society from imposing an efficient airplane noise tax based on the markups, *m*, at each airport is given by the standard formula

$$\tfrac{1}{2}\,\mathrm{TR}\epsilon m^2,$$

where TR is annual airline industry revenues and ϵ is the passenger demand elasticity.[36] We use average annual industry revenues from 1990 to 1995, $88.7 billion (1995 dollars), a demand elasticity of (minus) 0.7, and a weighted average of the square of the markups at each airport to obtain an annual welfare gain of $0.013 billion, or a present discounted welfare gain

[35] These figures are based on formulae presented in the Federal Aviation Regulations (FAR) Part 150 guidelines. A typical Stage II 727-200 departure, for example, constitutes a 100-dBA event at a house beneath the flight path 5 miles from the airport. An event (arrival or departure) of this type adds roughly 0.02 dBA to the daily noise level at that house, considering the possibility that the event may be a more heavily weighted nighttime flight and the fact that the effective perceived noise levels for arrivals are slightly higher than for departures for a given plane type.

[36] This calculation assumes that fares equal (private) marginal cost. Although there are routes (for example, involving "fortress" hubs) where fares are arguably above marginal cost, the airline industry as a whole does not appear to earn supranormal profits over the business cycle. During the last 20 years, the industry has earned an average annual rate of return on investment of 5.7 percent, which approaches a normal return.

of $0.184 billion.[37] Note that this calculation does not account for any adjustments that airlines would make to their equipment in response to the tax (for example, buying quieter planes to reduce or avoid the tax). But given that the findings of this paper imply that the costs of quieter planes to airlines exceed their benefits, as reflected in lower tax payments, such a response is unlikely.

Because the tax would result in a transfer payment to homeowners from carriers and passengers, homeowners would gain substantially more than $184 million. Nonetheless, the potential social net benefits from efficiently internalizing the airplane noise externality appear to have been quite small from the very start.[38] By significantly overshooting the mark, the FAA has cost society $5 billion.

A marginal-cost noise tax represents an efficient pricing solution. Noise permits, on the other hand, constitute an efficient "quantity" solution. Assuming no uncertainty, an efficient noise tax and an efficient noise permit would produce the same (small) welfare gain. Our estimate of the difference between the marginal private cost of a flight and its marginal social cost, $127, suggests that an efficient permit that allowed a flight to operate daily in perpetuity would sell for roughly $660,000, assuming a 7 percent discount rate. In a world of uncertainty, Martin Weitzman showed that quantities are a preferred policy instrument to prices if and only if the benefit function has more curvature than the cost function.[39] This is plausible for aircraft noise because noise reductions below 65 dBA provide minimal benefits. Nonetheless, the welfare gains from using noise permits are still likely to be small.

An efficient airplane noise policy produces a small estimated welfare gain because noise costs represent such a small portion of the social costs of airline travel, which include the operating costs of providing air service and the capital costs of aircraft. Air travel behavior is therefore very inelastic with respect to the costs of airplane noise, which suggests that an efficient noise tax (or permit) would be unlikely to influence traveler and carrier behavior in ways that would reduce airplane noise. This is certainly not

[37] The demand elasticity is based on Steven A. Morrison & Clifford Winston, The Evolution of the Airline Industry (1995). The average square of the markups is 0.0004. This is greater than squaring the average markup.

[38] We do not account for additional benefits from an optimal airplane noise tax that are reflected in new location choices and revised property values. On the other hand, these benefits are difficult to estimate and unlikely to change our qualitative conclusion. Nelson, *supra* note 1; Roy Nierenberg, Incentives versus Regulations: The Case for Airport Noise Charges, 2 Geo. Mason U. L. Rev. 167 (1978); and David Harrison, Jr., The Regulation of Aircraft Noise, in Incentives for Environmental Protection (Thomas C. Schelling ed. 1983), also find small welfare gains from federal policies toward airplane noise.

[39] Martin Weitzman, Prices vs. Quantities, 41 Rev. Econ. Stud. 477 (1974).

the case for all transportation externalities. For example, an efficient automobile congestion toll would represent a moderate fraction of automobile travelers' commuting costs and thus reduce congestion by discouraging some automobile travelers from commuting during peak travel periods.

The rational behavior of homeowners may also explain why the potential welfare gains from an efficient noise tax are small. People often take measures to minimize the cost of externalities without any prodding from the government. For example, John Calfee and Clifford Winston point out that commuters try to minimize the costs of automobile congestion by living closer to work, using public transit, commuting during off-peak travel periods, and so on.[40] In the case of airplane noise, we expect that people who have a high tolerance for noise would be willing to live closer to a flight path and require less compensation, as reflected in lower housing prices, than people who have a low tolerance for noise.

The ANCA imposed particularly severe costs on carriers because it influenced production decisions after long-run investments in Stage II planes had been made. Thus, the overwhelming fraction of the ANCA's cost to society is incurred in the value of lost capital investments.[41] Given the magnitude of these costs, both carriers and homeowners would probably have been better off if air carriers (or airports) had the option to pay homeowners for the right to fly Stage II planes.[42]

The ANCA represented a far too broad-brush approach to airport noise by failing to recognize that changes in the air travel market affect airports in different ways. For example, in an effort to stimulate airline competition, some policy makers are suggesting that additional takeoff and landing slots be made available at Washington's Reagan National and Chicago's O'Hare airports. This proposal has prompted complaints that airplane noise would increase. While the complaints are legitimate, current federal airplane noise regulation is silent on this issue because it simply requires industry fleets to meet Stage III noise requirements.

Final Comments

From a political point of view, airplane noise regulations may be doing what they are intended to do; that is, the magnitude of transfers from airlines and air travelers to homeowners is apparently a better indicator of

[40] John Calfee & Clifford Winston, The Value of Automobile Travel Time: Implications for Congestion Policy, 69 J. Pub. Econ. 83 (1998).

[41] The costs of the ANCA would have been lower if carriers had been given a longer transition time to meet the Stage III requirements.

[42] Property rights were assigned by a 1962 Supreme Court decision (Griggs v. Allegheny County), which made airport owners liable for noise damages awarded to property owners.

noise regulation's political attractiveness than its efficiency effects. But the political climate may be changing, as evidenced by the current debate over regulatory reform that clearly recognizes that the costs of many social regulations exceed their benefits. Airplane noise regulation should be added to the list.

APPENDIX

The Cost of the ANCA Based on Retrofitting

As indicated previously, it is difficult to obtain precise estimates of the costs of noise regulations based on the cost of retrofitting planes with hush kits. Rough estimates of these costs from industry sources based on the cost and installation of the hush kit, the extent of aircraft structural modifications and changes in flight operations, and so on suggest that these costs can easily exceed $10 million per plane. We do not know at which point during the transition period retrofitting would occur, which makes it difficult to calculate present values, but given that the ANCA requires replacing or retrofitting roughly 1,000 aircraft that would remain in service in the absence of regulation, it appears that an estimate of the costs of this regulation based on the cost of retrofitting would be comparable to our base case estimate of the cost of fleet replacement.

Sensitivity of the Cost Estimates to Assumptions That the Capital Stock Declines at a Geometric Rate and That Industry Output Is Fixed

The ANCA forces carriers to sell any remaining Stage II planes for "scrap" value or to foreign airlines in the year 2000, which would fully exhaust their initial Stage II capital stock. Because our model assumes that the Stage II capital stock depreciates at a geometric rate, it can never reach zero. As noted earlier, our model implies that roughly 3.5 percent of the total initial capital stock will remain in Stage II planes in the year 2000. This capital stock amounts to $2.99 billion, which according to our model is discounted by carriers over an *infinite* time horizon and yields a present discounted cost of $0.70 billion. In fact, carriers must sell their remaining Stage II aircraft for scrap value or to foreign airlines in the year 2000. If they receive no money for these planes, they will lose the full present discounted value (from the year 2000) of $2.99 billion, which is $1.57 billion. In this case, our estimate of the cost of the ANCA is understated by $0.87 billion ($1.57 billion minus $0.70 billion). If each of the 2,039 Stage II aircraft we estimate to be in U.S. fleets were sold for roughly $670,000 in the year 2000, then the carriers would incur a cost from the ANCA roughly equal to what we find in the base case. An examination of our data indicates that this figure is reasonably close to aircraft values the year before they are salvaged, retired, or sold abroad. Thus, it is unlikely that our estimates of the ANCA are significantly affected by not explicitly accounting for scrap value.

Our findings are also hardly affected if we account for travelers' downward-sloping demand curve, which enables carriers to adjust their output in response to the costs imposed by the ANCA. To show this, we first note that the annual cost of the ANCA over 9.167 years is $1.48 billion. This translates into an average cost increase per flight of $204 dollars and a cost markup of 1.5 percent ($204/$13,145, where $13,145 is the average cost (in 1995 dollars) of a flight in 1990 without the

ANCA in effect, calculated from data in the Air Transport Association 1996 Annual Report). Assuming that average costs equal marginal costs and that travelers' price elasticity of demand is -0.7,[43] output would fall 1.1 percent if carriers passed on the marginal cost of the ANCA in higher fares to travelers. This would reduce the initial value of the carriers' capital stock 1.1 percent, which reduces the present value of the cost of the ANCA to $9.9 billion (1995 dollars).

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[43] Morrison & Winston, *supra* note 37.

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