



PARTNERSHIP  
FOR AMERICA'S  
ECONOMIC  
SUCCESS

Issue Paper #11

# Childhood Lead Poisoning: Conservative Estimates of the Social and Economic Benefits of Lead Hazard Control

By  
Elise Gould, Economic Policy Institute



This report was made possible by generous support from the Partnership for America's Economic Success, the California Endowment, and the William Penn Foundation. I am grateful to Alexander Hertel-Fernandez, David Ratner, and Matthew Walters for excellent research assistance, and Josh Bivens, David Jacobs, Carol Emig, and three anonymous reviewers for constructive comments.

**The Partnership for America's Economic Success** was created by a group of business leaders, economists, advocates, and a dozen funders in order to document the economic impacts to the nation of proven investments in children from before birth to age five. The Partnership has been funded by the Buffet Early Childhood Fund; Robert Dugger; George Gund Foundation; Horace Hagedorn Foundation; Paul Tudor Jones; Ohio Children's Foundation; Peppercorn Foundation; The Pew Charitable Trusts; PNC Financial Services Group, Inc.; Scholastic, Inc.; The Schott Foundation for Public Education; and Anonymous. The Partnership is managed by The Pew Charitable Trusts.

901 E Street, NW, 10<sup>th</sup> Floor Washington, DC 20004  
(202) 552-2000 [www.PartnershipforSuccess.org](http://www.PartnershipforSuccess.org)

*Competing interests declaration:* The author declares that she has no competing financial interests with respect to this manuscript.

*Running Title:* Economic benefits of lead hazard control

*Key words:* cost/benefit, economics, housing, lead poisoning

*List of abbreviations and definitions:*

ADHD = Attention Deficit Hyperactivity Disorder

BLL = blood lead level

CDC = Center for Disease Control and Prevention

IQ = Intelligence Quotient

NHANES = National Health and Nutritional Examination Survey

*Article descriptor:* Children's health

## Contents

Abstract	5
Introduction	6
Incidence of low-level childhood lead poisoning	7
Sources of lead and costs of lead hazard control	9
Lead paint in housing	9
Benefits to reduction	11
Health care costs	11
Social and behavioral cost	12
IQ and lifetime earnings	12
Special education	13
Behavior and crime	14
Discussion	16
Conclusions	17
References	18
Tables	24

## Abstract

**Introduction:** This study is a cost-benefit analysis which quantifies the social and economic benefits to household lead paint hazard control as compared to the investments needed to minimize exposure to these hazards. **Methods/Results:** This research updates estimates of elevated blood lead levels among children 6 and under and compiles recent research to determine a range of the costs to lead paint hazard control (\$1 to \$11 billion) and the benefits of reduction attributed to each cohort for health care (\$11 to 53 billion), lifetime earnings (\$165 to \$233 billion), tax revenue (\$25 to \$35 billion), special education (\$30 to \$146 million), ADHD (\$267 million), and the direct costs of crime (\$1.7 billion) **Conclusions:** Each dollar invested in lead paint hazard control results in a return of \$17 to \$221 or a net savings of \$181 to \$269 billion. **Discussion:** There are substantial returns to investing in lead hazard control, particularly targeted at early intervention in communities most likely at risk. Given the high societal costs of inaction, lead hazard control appears to be well worth the price.

## Introduction

Lead poisoning is a serious hazard for children, causing significant biological and neurological damage linked to cognitive and behavioral impairment (Bellinger 2008a, 2008b). The level of lead exposure has fallen dramatically over the past thirty years due to the reduction of lead content in gasoline, household paint, food canning, industrial emissions, water lead, and other source reductions coupled with public health and housing initiatives. According to the National Health and Nutritional Examination Survey (NHANES), a population survey administered by the Center for Disease Control and Prevention (CDC), the geometric mean for blood lead levels (BLLs) for children six and under fell from 14.9 µg/dL (micrograms per deciliter) in 1976 to 1.6 µg/dL in 2006. The number of children under the age of six with BLLs at least 10 µg/dL has fallen from an estimated 13.5 million to 194,000 over the same period (NHANES 2003--06).

Recent research has indicated that significant neurological damage to children occurs even at very low levels of exposure (Lanphear et al. 2005; Chen et al. 2007; Bellinger 2008a, 2008b). Preventing these levels of exposure in young children will require controlling a significant and persistent cause of lead poisoning: lead paint used in housing prior to its ban in 1978. While pre-1950 house paint has the largest concentration of lead based paint hazards, house paint produced in 1950-1978 also contains substantial lead content. Poor, urban minorities disproportionately reside in these housing units, creating significant inequity in health and neurological outcomes by ethnicity and socioeconomic status (CDC 2004). Since the costs of lead paint abatement are nontrivial and the removal must be done on a unit by unit basis (rather than imposed at an industry level), there must be substantial commitment to further reduce lead poisoning among vulnerable children.

A growing body of literature has detailed the economic costs and risks of lead poisoning including several analyses summarizing these costs and setting them against the estimated costs of lead paint hazard control. However, recent research has broadened still the scope of our understanding of the societal costs of lead poisoning. For example, new studies have begun to analyze the correlation of lead poisoning to crime rates and their associated costs, as well as linking early lead exposure to adult-onset health problems. This paper aims to comprehensively address the costs and benefits of household lead hazard control vis-à-vis new discoveries in the medical, psychological, and economic literature. The focus is on children six and under because lead exposure is the highest for this age group and this is the period when lead exposure produces the most significant damage.

In this analysis, an upper and lower bound is constructed on the cost-effectiveness of strategies to reduce lead exposure. The reasoning behind this methodology is that there is no single estimate that accurately reflects either the costs or benefits to lead hazard control. On the costs side, the actual expense of reducing lead paint hazards in affected homes varies with the extent of interventions required. On the benefits side, the number of children with lead exposure ranges from those reported in state child blood lead surveillance data to those determined from weighted estimates of national surveys. While several factors could make one extreme or another more credible, it is likely that the truth lies in this interval.

## Incidence of low-level childhood lead poisoning

While the attention on lead and children has historically focused on blood lead levels of 10 µg/dL and higher, recent evidence suggests that lower levels incur high individual and societal costs. Though community-wide, medical, and environmental interventions have generally been initiated at a blood lead level of 10 µg/dL, the government has found that there is no level of exposure to lead below which adverse health effects do not occur (CDC 2004). Blood lead levels between 2 and 10 µg/dL have been found to cause persistent cognitive damage and children with BLL's in this range are likely to benefit from aggressive intervention. Table 1 compares the composition of children with blood lead levels between 2 and 10 µg/dL with the demographic patterns of the six and under population in general. Given limited sample sizes in the data, it is inadvisable to independently measure the characteristics of the population with levels above 10 µg/dL.

Out of the 27.97 million children six and under in the U.S. in 2006 (Census, 2008), 24.7 percent, or 6.9 million, have blood lead levels between 2 and 10 µg/dL (NHANES, 2003-06). Males, Hispanics, Blacks, and children in households below 200 percent of the federal poverty line are disproportionately more likely to have higher than average lead exposures.

### Causality of Lead Effects

#### *Lead and IQ*

Research over the past three decades has thoroughly documented the toxicant effects of lead on animal nervous systems (White et al 2007). Until recently, however, some had contested the association of lead exposure with brain damage and lower IQ in humans, claiming that other confounding factors were actually responsible for the primary neurological effects of lead. Recent research utilizing brain imaging has largely refuted such claims, demonstrating structural changes in the brains of lead-exposed children and adults, such as edema, herniation, and atrophy (Cecil et al 2008). Furthermore, previous work has also documented fundamental changes in the way brain pathways were activated in lead-exposed individuals (Yuan et al 2006). Neurological trauma, as well as reductions in brain size and function, has well documented effects on performance indexes as crude as IQ (Yuan et al 2008). Based on this evidence, it is reasonable to claim with confidence that lead has primary causal effects on neurological development that can lead to lower IQ levels.

#### *Lead and Special Education*

To be sure, the diagnosis of mental retardation involves much more than performance on a crude test of intelligence but the fact remains that IQ score is the most important predictor of mental retardation and remains the accepted standard for diagnosis. Indeed, the American Psychiatric Association's Diagnostic and Statistical Manual of Mental Disorders defines mental retardation by IQ score ranges with the recommendation of enrollment in special education. Therefore, given lead's primary effects on IQ, it is reasonable to claim that lead exposure also has first-order effects on special education.

### *Lead and Crime*

A host of prior psychological and sociological research has documented that delinquents (especially repeat offenders) have IQ levels that are nontrivially lower than the general population. This relationship holds constant and significant even after extensive socioeconomic, educational, and developmental controls. Psychiatrists since have identified lowered IQ as a risk factor for repeated antisocial behavior, including crime, finding that low levels of IQ reduce executive functioning, reasoning, and impulse control (Rutter et al 1998). In light of lead's effect on IQ, it is reasonable to hypothesize that increased lead exposure, especially in childhood, may raise an individual's risk factors for committing crimes and other antisocial behavior. This hypothesis has indeed been borne out by repeated studies (Wright 2008).



## Sources of lead and costs of lead hazard control

While bans on leaded gasoline and paint have greatly reduced the incidence of dangerous lead levels in children, many children are still at risk for damaging lead exposure. Lead paint and the related dust and chips are the leading cause of high lead levels in US children (Levin et al 2008). Nontrivial sources of lead poisoning are contributed by lead-contaminated water, soil, and dust, although the condition of lead-based paint is a strong predictor of lead in house dust (Lanphear et al 1998).

Other incidental sources of household lead exposure include the manufacture of stained glass, glazed pottery, remodeling homes, and toys or pottery containing lead-based paints (Mid-Atlantic Center for Children's Health and the Environment, 2003), certain calcium supplements including antacids and infant formula (Scelfo et al, 2000), and second-hand smoke (Mannino et al, 2003). Levin et al (2008) documents additional sources of lead exposure in eating utensils, breast milk, chocolate, candy, and other imported foods and related packaging.

Unfortunately, assessing the costs of removal of all lead hazards is difficult, and therefore, this analysis is restricted to the most common source of dangerous lead in children's environments: lead-based paint. While an adjustment for this assumption is posited in the final sections of this paper, this restriction downwardly biases the costs estimates, inflating the return on investment.

### *Lead Paint in Housing*

Lead paint was frequently used in housing units until its ban in 1978; occupants of pre-ban houses are at a significantly greater risk for lead exposure. For these older housing units, the US Department of Housing and Urban Development's lead guidelines (HUD 1995) list several methods of safely controlling the lead hazard possibilities including paint stripping, replacement, encapsulation, and enclosure. Jacobs et al (2003) presents a case study in which the costs of improper lead based paint removal were examined. They found the cost of decontamination after uncontrolled power sander use to be \$218,320 for a single house, greatly exceeding the incremental costs of incorporating lead-safe work practices into repainting, a cost they estimated to be \$1,200 for the individual homeowner (in 2006 USD).

A President's Task Force (2000) on childhood lead poisoning estimates the costs for two methods for controlling lead-based paint hazards. The first is lead hazard screening and interim controls, estimated to cost \$1,200 per housing unit. The second method is inspection, risk assessment, and full abatement of lead paint, estimated to cost \$10,800 per housing unit. Because of the variation in abatement requirements, regional differences in costs, condition of housing stock, and variation in the costs of adequate supervision and regulation of such work, the costs of lead hazard control can best be identified by a range rather than a precise estimate. Using the lower and upper bound values found in the President's Task Force (2000), it is likely that the true cost lies in the range of \$1,200 to \$10,800 per housing unit. This is line with Korfmacher's (2003) finding that the national average cost of making housing lead-safe is \$7,000 per unit.

According to the Department of Housing and Urban Development (2002), 38 million US homes have lead paint, of which 24 million housing units were deemed to be have lead hazards in 2000 (Jacobs et al. 2002). Four million of these homes have young children, and 1.2 million houses are at significant risk, with low income families and children 6 and under. Linearly extrapolating predicted reductions in units at risk of lead paint hazards from the President's Task Force (2000), 1.02 million homes are at significant risk in 2006. Targeting these 1.02 million homes most in need and using the bounds on costs of \$1,200 to \$10,800 per housing unit, the estimated cost lies between \$1.2 billion to \$11.0 billion.

## Benefits to reduction

### *Health Care Costs*

High lead levels can cause multiple and irreversible health problems, which include learning disabilities, Attention Deficit-Hyperactivity Disorder (ADHD), mental retardation, growth stunting, seizures, coma, or, at high levels, death. Previous studies have identified damaging effects of lead on the nervous, hematopoietic, endocrine, and renal systems (Bernard, 2003).

Treatment for low lead levels entails continuously monitoring blood levels and prevention of further exposure, while higher lead levels require chemical chelation to leach lead from the body, an expensive, time consuming, and painful procedure. Kemper et al (1998) provide the most comprehensive assessment of health care costs. They estimate the cost for CDC's prescribed medical interventions at each blood lead range.

Kemper et al (1998) estimate costs of screening and treatment as follows: venipuncture (\$8.57), capillary blood sampling (\$4.29), lead assay (\$23), risk assessment questionnaire (\$2), nurse-only visit (\$42), physician visit (\$105), environmental investigation and hazard removal (\$440), oral chelation (\$332), and intravenous chelation (\$2,418). These costs have been inflated to 2006 USD using the overall Consumer Price Index, an arguably conservative estimate of medical inflation as medical costs have increased at rates significantly higher than general inflation over the past decade. As children's blood lead levels increase, so do their medical costs. Based on Kemper et al (1998)'s assumptions and the CDC recommendations, it is possible to estimate the health costs per child given the levels of lead found in the population.

While there is no blood lead level below which adverse health effects have not been observed (Bernard 2003, Binns et al 2007, Brown 2007), the costs of medical diagnostics, prevention, and treatment for those with BLLs below 10 µg/dL are not included in this analysis as the medical costs of treating those below this CDC intervention level have not been fully assessed in the literature. To the extent that this omission is substantial, the medical benefits to lead hazard control are underestimated. This analysis also assumes that children who need treatment receive treatment immediately. If treatment now delays future health problems and thus costs, then the medical benefits are again underestimated.

For children with levels ranging from 10 to 20 µg/dL, further diagnostic testing is required, necessitating venipuncture and a lead assay, followed by an additional nurse-only visit, for a total cost of \$74 per child. For children with levels ranging from 20 to 45 µg/dL, the CDC recommends eight visits for diagnostic testing, including a nurse follow-up, and environmental investigation of the home in question, for a total cost of \$1,027 per child. For children with blood lead levels of 45 to 70 µg/dL, the recommended regime includes all of the above, accompanied by oral chelation for a total cost per child in this range of \$1,335. For children with levels 70 µg/dL or greater, oral chelation is replaced with intravenous chelation for a total cost of \$3,444 per child.

The estimated number of children affected in each group is a combination of two sets of data: pooled National Health and Nutrition Examination (NHANES 2003-06) and state child blood

lead surveillance data from the National Center for Environmental Health (CDC 2007). Given the relatively low level and non-representative nature of state-level testing, the 39,526 children with blood lead levels over 10 µg/dL (as reported by the states) represent an absolute lower bound of prevalence. According to analysis of NHANES 2003-06, there are 194,227 children with blood lead levels over 10 µg/dL. Because small sample sizes prevent accurate categorizing of children into each sub-grouping of blood lead level, the upper bound is extrapolated by applying the ratio of confirmed cases in the CDC state-level surveillance data to the numbers found in the NHANES and applying it to each subgroup. For example, since 39,526 is 20.35% of 194,227, the upper bound of children affected in the 10 to 15 µg/dL group is 24,554 confirmed cases divided by 20.35%, or 120,656 children. Table 2 reports the health care costs and incidence by blood lead level groupings. Summing across groups, the total cost of treatment is between \$10.8 and \$53.1 million.

The estimated range only includes the direct lead treatment costs for children six and under. Lead poisoning causes negative health effects later in life such as neurological disorders, adult hypertension, heart disease, stroke, kidney malfunction, elevated blood pressure, and osteoporosis (Korrick et al. 2003; Latorre et al. 2003; Muntner et al. 2005). Many of these conditions are chronic illnesses that must be managed throughout an individual's life course with either expensive pharmaceuticals or continual medical interventions. The biological effects of lead poisoning do not appear to affect all populations equally. Mexican and African American populations possess a disproportionately strong relationship between elevated lead levels and hypertension, among other arterial diseases (Muntner et al. 2005).

### *Social and Behavioral Costs*

The most well-established area of research on the effects of blood lead levels on children and society centers around the relationship between high blood lead levels and cognitive and behavioral impairment. Even low levels of exposure appear to lower children's intelligence quotient (IQ), which increase the need for enrollment in special education services, reduce the likelihood of high school and college graduation, lower lifetime earnings (both through educational and IQ pathways), and greatly increase their propensity to engage in violent criminal activity. This section examines each of these factors in turn, assessing the evidence and determining the costs of lead exposure to the individual and society.

### *IQ and lifetime earnings*

A variety of studies analyze the effects of high blood lead levels on intellectual function, most frequently quantified by IQ. Lanphear et al. (2005) establish a clear non-linear, negative relationship between IQ and BLL based on pooled international data. The rate of IQ loss is greatest per unit blood lead below 10 µg/dL.

Data from NHANES (2003-06) and state-level surveillance of lead poisoning (CDC 2007) determine the number of children six and under affected at each BLL from 2 µg/dL and over (Table 3). The average blood lead level for the 2 to 10 µg/dL group is based on the NHANES (2003-06), the average blood lead level for the 10 to 20 µg/dL group is taken at the mid-point, assuming a uniform distribution of lead levels within the group, and the average blood lead level

for the 20 µg/dL plus group is taken at 20 µg/dL. The small sample size does not allow for accurate estimates of average levels above 10 µg/dL, however, the assumption of the minimum is most conservative. Average IQ loss per 1 µg/dL is derived from the findings of Lanphear et al. (2005), assuming an even distribution of IQ loss *within* each BLL group.

Total IQ loss is computed for each BLL group, summed, and then multiplied by the estimated number of children affected. IQ loss from elevated blood lead levels falls between 9.3 and 13.1 million points. While these losses have severe social and behavioral consequences, they also carry a significant financial burden of lost lifetime earnings.

Drawing from Schwartz (1994), Salkever (1995), and Nevin (2008), each IQ point loss is found to represent a loss of \$17,815 in present discounted value of lifetime earnings (in 2006 USD). Using the previously computed total IQ loss of 9.3 to 13.1 million points, net lifetime earnings loss is calculated to fall between \$165 and \$233 billion for all children six and under in the 2006 cohort. This estimate includes the indirect effects of lower educational achievement and workforce participation in addition to the direct effect of lower hourly wages.

With every loss in lifetime earnings comes an associated loss in potential tax revenue for the government. Korfmacher (2003), using the methodology of Grosse et al (2002), estimates that the state of New York is losing nearly \$78 million in tax dollars each year due to lowered earnings from lead poisoning. If we perform the same exercise with a 15% marginal tax, lost tax revenue from lead poisoning is estimated to be \$25 to \$35 billion for each cohort of lead poisoned children.

### *Special Education*

Children with high lead levels are in need of special education because of their slower development, lower educational success, and related behavioral problems. Schwartz (1994) found that 20 percent of children with BLL over 25 µg/dL needed special education. He suggests these children's needs span an average of three years, requiring assistance from a reading teacher, psychologist, or other specialist. Korfmacher (2003) estimated that the average annual cost of special education is \$14,317 per child (inflated to 2006 USD).

Based on Schwartz (1994a)'s findings, 20 percent of children over 25 µg/dL is estimated to fall between 693 and 3,404 children (using the same bounds analysis as described previously). Multiplying out these factors with the average cost per child for three years of special education, it costs an estimated \$30 to \$146 million for each cohort of lead-poisoned children.

In addition to the relationship of reduced IQ on lifetime earnings and the additional investments required in special education, research indicates adverse effects of lead exposure directly on educational achievement and children's readiness for school (Rothstein, 2004). In addition, studies have found significant and negative effects of early and minimal lead blood exposure on statewide exam scores, in the same order of magnitude as the effect of poverty (Miranda et al. 2007).

Elevated BLLs are associated with an increased risk of not completing high school (Needleman 2004). Cohen et al (1998) quantify the effects of dropping out of high school on lowered lifetime earnings and increased criminal activity. While there may be a direct link between elevated lead levels and high school completion, this analysis chooses to avoid any potential double-counting and assumes that these effects are included indirectly in the earnings and criminal activity discussions. Excluding the nonmarket benefits of education (Haveman and Wolfe 1984) leads to an underestimate of the benefits to lead hazard control.

Research by Braun et al. (2006) have quantified the long-observed association between childhood lead exposure and development of ADHD. ADHD is a highly prevalent, lifelong psychiatric disorder that places children at an increased risk for conduct disorder, antisocial behavior, criminal activity, and drug abuse (Costello et al. 2003). Prevalence is estimated at 3 to 8 percent of children fifteen and under (CDC 2005). ADHD is managed through a combination of prescription drug therapy and counseling sessions for children and more severe adult cases. In addition to high lifelong treatment costs, ADHD also extracts significant productivity costs for parents of ADHD children. Work by Birnbaum (2005) finds that the parents of an ADHD child collectively incur approximately \$5 billion in work and productivity losses.

The total cost of lead-linked ADHD cases in the United States is found by computing the number of ADHD cases annually linked to early lead exposure from Braun et al.'s study (2006). Out of the 1.8 million ADHD cases in children 4-15 years of age, 21.1 percent, or 290,000, are linked to blood lead levels above 2 µg/dL (Braun et al 2006). Assuming average medical treatment costs per child of \$565 for drug and counseling therapy and average parental work loss costs of \$119 per child, lead exposure costs \$267 million annually to individual families and society. Because the costs of medical treatment and work losses are likely to greatly increase with the severity of the condition, these estimates represent a conservative lower bound for the total costs of lead-linked ADHD cases.

### *Behavior and Crime*

Medical and economic research has established a connection between early childhood lead exposure and future criminal activity, especially of a violent nature. Bellinger et al. (1994) find that increased lead exposure correlates strongly with social and emotional dysfunction. Needleman et al. (1996) examine schoolchildren between the ages of 7 and 11 years old who have had a clinical diagnosis of lead poisoning at an early age, and find worsening of behavior patterns as high-blood level children aged. Needleman et al. (2002) indicate that adjudicated delinquents are four times more likely to have blood lead concentrations over 25 parts per million than non-delinquent adolescents.

Recent work by Wright (2008) examined a cohort of young adults from childhood, and found a considerably higher and significant rate of arrest, particularly for violent crimes, amongst young adults that had elevated lead exposures at an early age. These clinical findings confirm broader research that links lead exposure to antisocial and destructive behavior, both in humans and animal subjects alike (Denno 1990; Canfield et al. 2004; Froehlich, Lanphear et al. 2007; Surkan and Zhang 2007).

Nevin (2000) finds that the variation in childhood gasoline lead exposure from 1941 to 1986 explains nearly 90 percent of the variation in violent crime rates from 1960 to 1998, and that lead paint explains 70 percent of the variation in murder rates from 1900 to 1960. Reyes (2002) takes the evidence of a relationship between lead poisoning and criminal behavior and estimates that the Clean Air Act in the 1970s and 1980s accounts for one-third of the drop in crime throughout the 1990s.

Both clinical and econometric evidence suggest that lowered lead levels will lead to lower crime rates. The Federal Bureau of Investigation (Uniform Crime Reporting Program 2006) lists numbers of crimes per 100,000 residents and the Bureau of Justice Statistics (2004) estimates their associated direct costs. Using Nevin's (2006) estimate of the annual number of crimes that could have been averted with a 1 µg/dL reduction in the average preschool blood lead, the total direct costs of lead-linked crime can be computed.

A 1 µg/dL reduction in the average preschool blood lead level results in 116,541 fewer burglaries, 2,499 fewer robberies, 53,905 fewer aggravated assaults, 4,186 fewer rapes, and 717 fewer murders (Table 4). The total direct cost of lead-linked crimes is approximately \$1.8 billion, including direct victim costs, costs related to the criminal justice system through legal proceedings and incarceration, and lost earnings to both criminal and victim. An additional \$11.6 billion is lost in indirect costs, which includes psychological and physical damage necessitating medical treatment and preventive measures resulting from the criminal action. For the purposes of this conservative analysis, only the direct costs of each crime are considered. Furthermore, while these effects are for only a 1 µg/dL decrease, complete removal of lead hazards would have even larger effects.

The consequences of an antisocial and destructive pathology amongst lead poisoned children are not isolated to criminal activity alone. Recent research has indicated that moderate levels of childhood lead exposure can greatly increase an individual's propensity for risk-taking activities. For instance, Lane et al. (2008) find that lead levels over 20 µg/dL are strongly linked to repeat teenage pregnancies and cigarette smoking amongst low-income youth, both of which incur sizeable costs to individuals, families, and society.



## Discussion

To demonstrate the cost-effectiveness of lead hazard control, total benefits and costs of childhood lead level reduction are summed then compared. The costs of lead hazard control range from \$1.2 to \$11.0 billion. The benefits to lead hazard control is the sum of the costs for medical treatment (\$11 to \$53 billion), lost earnings (\$165 to \$233 billion), tax revenue (\$25 to \$35 billion), special education (\$30 to \$146 million), lead-linked ADHD cases (\$267 million), and criminal activity (\$1.7 billion) for a total of \$192 to \$270 billion. The net benefit of lead hazard control ranges from \$181 to \$269 billion, resulting in a return of \$17 to \$221 for each dollar invested in lead hazard control (Table 5).

The estimate of the benefits to controlling lead hazards presented in this paper is still quite conservative. The absolute lower bound of lead prevalence above 10 µg/dL uses state-level confirmed cases and excludes many important and potentially substantial costs. These include health care later in life, neonatal mortality, benefits of lead hazard control on property value and energy savings, community improvement, lead paint litigation, indirect costs to criminal activity, and other intangible benefits. Similarly, this analysis calculates the benefit for one cohort of US children while the duration of lead hazard controls are likely to endure for 6 or more years (Wilson et al 2006). Including future cohorts and assessing a full lifetime of costs would vastly increase the benefit to lead hazard control.

That said, while the major source, lead based paint is by no means the only source of dangerous lead exposures among children. If a similar distribution of lead exposures, or high and low blood lead levels, are found from both lead based paint and other types of lead hazards, a back of the envelope adjustment for other major sources of lead exposures on these benefits leads the final benefit range to decrease by 30% as lead based paint represents about 70% of childhood exposure to lead (Levin et al 2008). This leads to a net benefit ranging from \$124 to \$188 billion, resulting in a return of \$12 to \$155 for each dollar invested in lead paint hazard control.



## Conclusions

Public health and housing policy have been slow to address these remaining lead poisoning risks, moving incrementally with targeted, more re-active policies. If the cost of pro-active and universal lead hazard control is seen as prohibitive, the costs of inaction have proven to be significantly greater. For every dollar spent on controlling lead hazards, between \$17 and \$221 would be returned in health benefits, increased IQ, higher lifetime earnings, tax revenue, less spending on special education, and reduced criminal activity.

To put these results in perspective, it is useful to compare these net benefits to an intervention commonly understood as tremendously cost effective, that of vaccinations. Cost benefit analyses show that vaccination against the most common childhood diseases delivers large returns on investment, saving between \$5.30 and \$16.50 in costs for every dollar spent on immunizations (Zhou et al 2005). Given the high societal costs of inaction, lead hazard control as well appears to be well worth the expense.

## References

- Bellinger DC, Leviton AE, and Rabinowitz M. 1994. Pre- and Postnatal Lead Exposure and Behavior problems in School Age Children. *Environmental Research* 66:12-30.
- Bellinger DC. 2008a. Neurological and Behavioral Consequences of Childhood Lead Exposure. *PLOS Medicine* 5:e115.
- Bellinger DC. 2008b. Very low lead exposures and children's neurodevelopment. *Current Opinion in Pediatrics* 20:172-177.
- Bernard SM. 2003. Should the Centers for Disease Control and Prevention's Childhood Lead Poisoning Intervention Level be Lowered? *American Journal of Public Health*. 93:1253-1260
- Binns HJ, Campbell C, Brown MJ. 2007. Interpreting and Managing Blood Lead Levels of Less Than 10 µg/dL in Children and Reducing Childhood Exposure to Lead: Recommendations of the Center for Disease Control and Prevention Advisory Committee on Childhood Lead Poisoning Prevention. *Pediatrics*. 120(5): e1285-e1298.
- Birnbaum HG, Kessler RC, Lowe SW, Secnik K, Greenberg PE, Leong SA, et al. 2005. Costs of Attention Deficit-Hyperactivity Disorder (ADHD) in the US: Excess Costs of Persons with ADHD in 2000. *Current Medical Research Opinion* 21:195-205.
- Braun JM, Kahn RS, Freohlick T, Auinger P, Lanphear BP. 2006. Exposures to Environmental Toxicants and Attention Deficit Hyperactivity Disorder in Children. *Environmental Health Perspectives* 114:1904-1909.
- Brown MJ. 2007. Interpreting and Managing Blood Lead Levels < 10 µg/dL in Children and Reducing Childhood Exposures to Lead. *Morbidity and Mortality Weekly Recommendations and Reports* 56:1-14.
- Bureau of Justice Statistics, Department of Justice. 2004. "Cost of Crime." Washington DC: U.S. Department of Justice.
- Canfield RL, Gendle M, Cory-Slechta DA. 2004. Impaired neuropsychological functioning in lead-exposed children. *Developmental Neuropsychology* 26:513-540.

Center for Disease Control, National Center for Environmental Health. Children's Blood Lead Levels in the United States. Available: <http://www.cdc.gov/nceh/lead/research/kidsBLL.htm> [accessed 24 October 2008].

Centers for Disease Control. 2004. Preventing Lead Exposure in Young Children: A Housing-Based Approach to Primary Prevention of Lead Poisoning. Atlanta, GA: Centers for Disease Control and Prevention.

Centers for Disease Control. 2005. Mental Health in the United States: Prevalence of Diagnosis and Medication Treatment for Attention-Deficit/Hyperactivity Disorder --- United States, 2003. Available: <http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5434a2.htm> [accessed 18 November 2008].

Centers for Disease Control Childhood Blood Lead Surveillance Data. 2007. Tested and Confirmed Elevated Blood Lead Levels by State, Year, and Blood Lead Level Group, 1997-2006. Available: <http://www.cdc.gov/nceh/lead/>. [accessed 24 October 2008].

Chen AB, Cai B, Dietrich KN, Radcliffe J, Rogan WJ. 2007. Lead exposure, IQ, and behavior in urban 5-7 year olds: Does lead affect behavior only by lowering IQ? *Pediatrics* 119:e650-658.

Cohen MA. 1998. The monetary value of saving a high-risk youth. *Journal of Quantitative Criminol* 14(1): 5-33 (March).

Costello E, Mustillo M, Erhardt A, Keeler G, Angold A. 2003. Prevalence and development of psychiatric disorders in childhood and adolescence. *Archives of General Psychiatry* 60:837-844.

Census Postcensal Monthly Population Estimates, 2008. United States Census Bureau. Available: <http://www.census.gov/popest/> [accessed 6 March 2009].

Denno D. 1990. *Biology and violence*. New York:Cambridge University Press.

Froehlich T, Lanphear BP, Dietrich KN, Cory-Sleeta DA, Wang N, Kahn RS. 2007. Interactive effects of a DRD4 polymorphism, lead, and sex on executive functions in children. *Biology and Psychiatry* 62:243-249.

- Grosse SD, Matte TD, Schwartz J, and Jackson RJ. 2002. Economic Gains Resulting from the Reduction in Children's Exposure to Lead in the United States. *Environmental Health Perspectives*. 110:563-69.
- Haveman RH, and Wolfe BL. 1984. Schooling and Economic Well-Being: The role of nonmarket effects. *Journal of Human Resources* 19(3):377-407.
- Jacobs DE, Clickner RP, Zhou JY, Viet SM, Marker DA, Rogers JW. 2002. The Prevalence of Lead-Based Paint Hazards in U.S. Housing. *Environmental Health Perspectives*. 110:599-606.
- Jacobs DE, Mielke H, and Pavur N. 2003. The High Cost of Improper Removal of Lead-Based Paint from Housing: A Case Report. *Environmental Health Perspectives* 111:111-185.
- Kemper AR, Bordley WC, and Downs SM. 1998. Cost-Effectiveness Analysis of Lead Poisoning Screening Strategies Following the 1997 Guidelines of the Center for Disease Control and Prevention. *Archives of Pediatric Adolescent Medicine*. 152:1202-08.
- Korfmacher KS. 2003. Long-term costs of lead poisoning: How much can New York save by stopping lead? Working Paper: Environmental Health Sciences Center, University of Rochester.
- Korrick SA, Schwartz J, Tsaih SW, Hunter DJ, Aro A, Rosner B, et al. 2003. Correlates of Blood and Bone Lead Levels among Middle-Age and Elderly Women. *American Journal of Epidemiology* 156:335-343.
- Lane SD, Webster NJ, Levandowski BA, Rubinstein RA, Keefe RH Wojtowycz MA, et al. 2008. Environmental Injustice: Childhood Lead Poisoning, Teen Pregnancy, and Tobacco. *Journal of Adolescent Health* 42:43-49.
- Lanphear BP, Burgoon DA, Rust SW, Eberly S, Galke W. 1998. Environmental Exposures to Lead and Urban Children's Blood Lead Levels. *Environmental Research*. 76(2):120-30.
- Lanphear BP, Hornung R, Khoury J, Yolton K, Baghurst P, Bellinger DC, et al. 2005. Low-Level Environmental Lead Exposure and Children's Intellectual Function: An International Pooled Analysis. *Environmental Health Perspectives* 113:894-899.

- Latorre FG, Hernández-Avila M, Orozco JT, Albores-Medina CA, Aro A, Palazuelos E, et al. 2003. Relationship of Blood and Bone Lead to Menopause and Bone Mineral Density among Middle-Age Women in Mexico City. *Environmental Health Perspectives*. 111:631-636.
- Levin R, Brown MJ, Kashtock ME, Jacobs DE, Whelan EA, Rodman J, Schock MR, Padilla A, Sinks T. 2008. Lead Exposure in US Children, 2008: Implications for Prevention. *Environ Health Perspect*. 116:1285-1293.
- Mannino DM, Albalak R, Grosse S, and Repace J. 2003. Second-hand Smoke Exposure and Blood Lead Levels in U.S. Children. *Epidemiology*. 14:719-727.
- Miranda ML, Kim D, Overstreet Galeano MA, Paul CJ, Hull AP, Morgan SP. 2007. The Relationship between Early Childhood Blood Lead Levels and Performance on End-of-Grade Tests. *Environmental Health Perspectives* 115:1242-1247.
- Muntner P, Menke A, DeSalvo KB, Rabito FA, Batuman V. 2005. Continued Decline in Blood Lead Levels Among Adults in the United States. *Archives of Internal Medicine* 165:2155-2161.
- The Mid-Atlantic Center for Children's Health and the Environment. Available: <http://www.gwu.edu/~macche/parents/lead.html> [accessed 24 October 2008].
- National Health and Nutrition Examination Survey Data. 2003-06. Centers for Disease Control and Prevention. National Center for Health Statistics. Hyattsville, MD: U.S. Department of Health and Human Services.
- Needleman HL. 2004. Low Level Lead Exposure and the Development of Children. *Southeast Asian Journal of Tropical Medicine and Public Health* 35(2):252-254
- Needleman HL, McFarland C, Ness RB, Feinberg SE, Tobin MJ. 2002. Bone lead levels in adjudicated delinquents: A case control study. *Neurotoxicology and Teratology* 24:711-717.
- Needleman HL, Riess JA, Tobin MJ, Biesecker GE, Greenhouse JB. 1996. Bone Lead Levels and Delinquent Behavior. *Journal of American Medical Association* 275:363-369.
- Nevin R. 2000. How Lead Exposure Relates to Temporal Changes in IQ, Violent Crime, and Unwed Pregnancy. *Environmental Research* 83:1-22.

- Nevin R. 2006. Understanding international crime trends: The legacy of preschool lead exposure. *Environmental Research* 104:315-336.
- Nevin R, Jacobs DE, et al. 2008. Monetary benefits of preventing childhood lead poisoning with lead-safe window replacement. *Environmental Research* 106:410-419.
- President's Task Force on Environmental Health Risks and Safety Risks to Children. 2000. *Eliminating Childhood Lead Poisoning: A Federal Strategy Targeting Lead Paint Hazards (Report and Appendix)*. Washington DC: U.S. Department of Housing and Urban Development and U.S. Environmental Protection Agency. (accessed at <http://www.hud.gov/offices/lead/library/hhi/FedLeadStrategy2000.pdf>)
- Reyes JW. 2002. The Impact of Lead Exposure on Crime and Health; and an Analysis of the Market for Physicians. Dissertation: Harvard University Department of Economics.
- Rothstein R. 2004. *Class and Schools*. Washington, D.C.: Economic Policy Institute.
- Salkever DS. 1995. Updated Estimates of Earnings Benefits from Reduced Exposure of Children to Environmental Lead. *Environmental Research* 70:1-6.
- Scelfo GM and Flegal AR. 2000. Lead in Calcium Supplements. *Environmental Health Perspectives*. 108:309-313.
- Schwartz J. 1994. Societal Benefits of Reducing Lead Exposure. *Environmental Research*. 66:105-124.
- Surkan P and Zhang A. 2007. Neuropsychological functioning in lead-exposed children with blood lead levels <10 ug/dL. *Neurotoxicology* 28:1170-1177.
- Uniform Crime Reporting Program, Federal Bureau of Investigation. 2006. "Crime in the United States." Washington DC: U.S. Department of Justice.
- U.S. Department of Housing and Urban Development, HUD. 2002. *National Survey of Lead and Allergens in Housing Volume I: Analysis of Lead Hazards, FINAL REPORT, Revision 7.1*, October 31, 2002
- Wilson J, Pivetz T, Ashley P, Jacobs D, Strauss W, Menkedick J, et al. 2006. Evaluation of HUD-funded lead hazard control treatments at 6 years post-intervention. *Environ Res* 102:237-248.

Wright JP, Dietrich KN, Douglas Ris M, Hornung RW, Wessel SD, Lanphear BP, et al. 2008. Association of Prenatal and Childhood Blood Lead Concentrations with Criminal Arrests in Early Adulthood. PLOS Medicine 5:e101.

Zhou F, Santoli J, Messonnier ML, Yusuf HR, Shefer A, Chu SY. 2005. Economic Evaluation of the 7-Vaccine Routine Childhood Immunization Schedule in the United States, 2001. Arch Pediatr Adolesc Med. 2005;159:1136-1144.

Table 1. Demographics of Childhood Lead Poisoning<sup>a</sup>

	2 to 10 µg/dl	Share of total 6 and under population <sup>b</sup>
Children, 6 and under	24.7%	100.0%
Sex		
Male	53.6%	51.1%
Female	46.4%	48.9%
Race		
White, Non-Hispanic	47.4%	57.9%
Black, Non-Hispanic	23.6%	13.7%
Hispanic	24.6%	21.1%
Other	4.6%	7.3%
Income		
Up to 200% of Federal Poverty Line	60.2%	46.4%
200% to 400%	22.8%	29.2%
400% and over	17.1%	24.4%

<sup>a</sup> Source: Authors' analysis of NHANES (2003-06).

<sup>b</sup> Shares of 6 and under population by race do not match ratios in other data due to differences in sampling and definitions.



Table 2. Health Care Costs in 2006 USD<sup>a</sup>

Blood lead level	Cost of recommended medical action	Lower bound of affected children	Upper bound of affected children <sup>b</sup>	Lower bound cost	Upper bound cost
10 to 15 µg/dl	\$74	24,554	120,656	\$1,816,996	\$8,928,552
15 to 20 µg/dl	\$74	8,185	40,220	\$605,690	\$2,976,305
20 to 45 µg/dl	\$1,207	6,347	31,189	\$7,660,829	\$37,644,611
45 to 70 µg/dl	\$1,335	376	1,848	\$501,960	\$2,466,585
Over 70 µg/dl	\$3,444	64	314	\$220,416	\$1,083,104
All levels		39,526	194,227	\$10,805,891	\$53,099,158

<sup>a</sup> Kemper et al (1998) provides estimates for the costs of recommended action (inflated to 2006 USD).

<sup>b</sup> The upper bound values are calculated assuming that the the CDC state-level surveillance confirmed cases represent 20.35% of estimates over 10ug/dl derived from NHANES (2003-06): 39,536 confirmed cases to 194,227 cases as estimated from NHANES (2003-06).

Table 3. Lead and IQ<sup>a</sup>

Blood lead level	Lower bound of affected children	Upper bound of affected children	Average BLL per BLL group <sup>c</sup>	Average IQ loss per ug/dl <sup>b</sup>	Lower bound IQ loss	Upper bound IQ loss
2 to 10 µg/dl	5,632,147	7,400,920	3.13 µg/dl	0.513	9,043,482	11,883,583
10 to 20 µg/dl	32,739	160,876	~15 µg/dl	0.19	199,053	978,129
20 µg/dl plus	6,678	32,815	~20 µg/dl	0.11	46,946	230,690
Totals					9,289,482	13,092,402

BLL = Blood lead level.

<sup>a</sup> Data for children with BLLs under 10 µg/dl is estimated from CDC NHANES 2003-06. Data for children over 10 µg/dl is from state-level surveillance and assumes uniform distribution of cases within each BLL group. Lower and Upper Bound for 2 to 10 ug/dl group represents 95% confidence intervals for NHANES estimate. Italicized values calculated assuming that the the CDC confirmed cases represent 20.35% of all cases, given that CDC confirmed cases represent 20.35% of NHANES estimates for those over 10ug/dl.

<sup>b</sup> From Lanphear et al 2005; assume uniform decreases within BLL groups.

<sup>c</sup> Average BLL calculated for 2-10 ug/dl using CDC NHANES 2003-06, average BLL for 10 to 20 ug/dl taken as the mid-point, and average BLL for 20 and over ug/dl group uses the most conservative lower bound (the floor) for the mean.

Table 4: Lead and Crime

	All crimes per 100,000 residents <sup>a</sup>	Lead-linked crimes per 100,000 residents <sup>b</sup>	Total lead linked crimes	Direct costs per crime <sup>c</sup>	Total direct Costs
Burglaries	1,335.70	38.7	116,541	\$4,010	\$467,329,410
Robberies	213.7	0.83	2,499	\$22,871	\$57,154,379
Aggravated Assaults	352.9	17.9	53,904	\$20,363	\$1,097,628,286
Rape	37.6	1.39	4,186	\$28,415	\$118,945,567
Murder	8.3	0.238	717	\$31,110	\$22,305,512
Totals			177,847		\$1,763,363,153

<sup>a</sup> Calculated using crime incidence data from 2006 from the Federal Bureau of Investigation (Uniform Crime Reporting Program 2006).

<sup>b</sup> Data from Nevin 2006.

<sup>c</sup> Data from the Bureau of Justice Statistics (2004) for 2004; inflated to 2006 USD.

Table 5: Total Costs and Benefits to Lead Control

	Conservative estimate	Optimistic estimate
Total benefit from lead reduction	\$192.38b	\$270.45b
Total cost of Lead control	\$11.02b	\$1.22b
Total net benefit	\$181.37b	\$269.23b
Cost/benefit	1 to 17	1 to 221