Valuing the Benefits of Reducing Childhood Lead Exposure—Human Capital, Parental Preferences, or Both?

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Abstract

Early childhood lead exposure can impair neurobehavioral development. There is a well-documented relationship between increases in blood lead levels (BLL) and reduced IQ. Public health actions have been taken to reduce lead in drinking water including lead service line (LSL) replacement. This narrative review summarized two methods used in the literature to assign economic value to IQ—human capital approach and willingness to pay (WTP) approach. We used estimates from the literature in a case study that estimated the economic benefits of prevention of cognitive impairment caused by lead exposure in young children. In the case study, we made assumptions in the reduction in lead levels in drinking water after LSL replacement, corresponding reduction in blood lead levels, and IQ increases. We assigned monetary values to the increase in IQ using human capital and WTP approaches. Our review of literature in human capital approach shows that the proportional increase in earnings with increased cognitive ability may be in the range of 1.3% to 2.2% per IQ point. The present value of real earnings in early childhood likely increased by 1.5-1.8% per IQ point, which implies a range of $12,000 to $17,500 per IQ point in 2018 dollars, assuming a linear relationship. Those estimates place no economic value on cognitive ability applied to childrearing or other unpaid household services. For WTP estimates, we found one stated preference study in the peer reviewed literature that estimated WTP per IQ point to be $466 (2005 dollar). A working paper estimated parents' WTP to be $1,100 and $1,900 per IQ point gained. Based on human capital approach estimates, if more than one child benefits from LSL replacement in a house, the benefit will outweigh the cost. Based on the WTP estimates, there would need to be 4 to 21 children per house to break-even. When estimating the health benefits of reducing childhood lead exposure, the monetary value per IQ has the largest uncertainty comparing with other inputs used in the calculation. The large discrepancy from these two approaches is mainly due to the target for measurement and different perspectives. Estimates using these two approaches can complement each other. More WTP studies on this topic are needed to help fill in the gap in knowledge.

Keywords: economic value, willingness to pay, human capital, IQ, lead exposure

Introduction

Lead (Pb) exposure can affect nearly every system in the body. Children are especially at risk from lead exposure because of their small size and developing brains. No safe lead level in children has been identified (CDC 2019a). Early childhood lead exposure can impair neurobehavioral development. Even low levels of lead in blood have been shown to affect a child's intelligence quotient (IQ), ability to pay attention, and academic achievement (Chen et al. 2005; Lanphear et al. 2005). In particular, multiple high-quality epidemiologic studies summarized in a U.S. Environmental Protection Agency (EPA) report have demonstrated a causal relationship between blood lead level (BLL) and cognitive function decrements in children (EPA 2013).

Lead can be found in the air, the soil, the water, and past use of lead-based paint in homes. The recent crisis in Flint, Michigan shed light on the problem of lead in drinking water (Ruckart et al. 2019). EPA estimates that drinking water contaminated with lead can contribute to 20% or more of a person's total exposure to lead (EPA 2019a). Infants who consume mostly mixed formula can receive 40% to 60% of their total exposure to lead from drinking water. Lead can enter drinking water when plumbing materials that contain lead corrode, especially where the water has high acidity or low mineral content that corrodes pipes and fixtures (EPA 2019a). The most common sources of lead in drinking water are lead pipes, faucets, and fixtures. In homes with lead pipes that connect the home to the water main, also known as lead service lines (LSL), these pipes are typically the most significant source of lead in the water. Lead pipes are more likely to be found in older cities and homes built before 1986 (EPA 2019a). Among homes without lead service lines, the most common problem is with brass or chrome-plated brass faucets and plumbing with lead solder.

Actions have been taken to reduce lead in drinking water. For example, from 2004 through 2016, Lansing, Michigan, replaced 12,150 LSLs with copper lines at a cost of $44.5 million (Health Impact Project 2017). New York's Clean Water Infrastructure Act of 2017 requires the New York State Department of Health to implement a Lead Service Line Replacement Program (LSLRP) (New York State Department of Health 2018). Milwaukee requires full replacement of LSLs with copper pipes if a leak or failure is discovered or if the utility-owned portion is replaced (Health Impact Project 2017).

To estimate the economic value of efforts to reduce lead in drinking water, it is necessary to assign monetary values to expected improvements in health. In regulatory benefit-cost analyses (BCA), it is preferred to use preference-based estimates of societal willingness to pay (WTP) to reduce risks or willingness to accept (WTA) risks with monetary compensation. In particular, it is standard to use a WTP/WTA estimate of roughly $10 million per death averted to value deaths avoided by regulatory actions (Viscusi 2018). Lacking WTP estimates for nonfatal endpoints, it is common to use estimates of direct and indirect (productivity) costs associated with morbidity or disability to inform regulatory BCAs.

For economic assessments of childhood lead poisoning prevention, change in IQ scores, a measure of cognitive outcome, is the most commonly used outcome measure. Because of the well documented relationship between increases in BLL and reduced IQ, this study focused on two methods to assign economic value to IQ—avoided costs and welfare gains. Avoided costs included both direct and indirect productivity costs. Of particular relevance to lead is the loss in lifetime economic productivity associated with reductions in cognitive skills, also referred to as the human capital approach. Welfare gains are valued by economists using WTP/WTA estimates.

The objective of this study is to first review and summarize the estimates from the literature on assigning monetary values of an IQ point using human capital and WTP approaches. Then, we conducted a case study to estimate the economic benefits of prevention of cognitive impairment caused by lead exposure in young children based on these two approaches.

Methods

Human capital approach

In the human capital approach used in health economics, societal productivity costs associated with premature death or disability are calculated as the present value of lost future economic production, discounted using a social discount rate. Productivity is calculated in the literature as economic production at the national level, including anything that contributes to gross domestic product (GDP) plus the value of non-market services that are not included in GDP, e.g., child rearing and volunteer services. Similarly, future market production has been projected in published studies based on employment rates, life table survival probabilities, and projected gross (pre-tax) earnings (Grosse and Krueger 2011; Grosse et al. 2019a; Pike and Grosse 2018). Updated estimates of annual and lifetime productivity for the US population stratified by age and sex were recently published based on 2016 data (Grosse et al. 2019a). The lifetime estimates of gross market earnings, which include payroll taxes and monetary benefits, for an infant in 2016 were estimated as $0.8-0.9 million assuming a 3% discount rate and future growth in real earnings of 0.5-1.0% per year (Grosse et al. 2019a). The monetary value of nonmarket production is typically imputed on the basis of time use data with hours conservatively valued using the replacement cost approach (Grosse et al. 2019a; Grosse et al. 2019b). Lifetime total productivity is estimated as $1.2-1.5 million in 2016 (Grosse et al. 2019a).

Anything that reduces individuals' employment and earning capacity, even if not associated with overt disability, has an adverse economic impact on overall societal productivity. For example, if a 1 IQ point reduction is estimated to be associated with a 1% reduction in future earnings, one can multiply the present value of future earnings, roughly $900,000, by 1% to calculate the expected loss of future market productivity, or $9,000.

The sources of published estimates summarized in the Results section are derived from previous reviews of the literature on estimates of the IQ-earnings association published through 2014 (Grosse 2007; Grosse 2014) supplemented by searches of Google Scholar and PubMed for more recent studies.

Willingness to pay approach

WTP for a health improvement program or policy is the aggregation of the maximum amounts of money individuals would voluntarily pay to obtain the improvement, given their budget constraints (Robinson and Hammitt 2013). There are the two ways to measure WTP—revealed preference and stated preference approaches. Revealed preference methods draw statistical inferences on values from actual choices people make within markets, e.g., compensating wage differentials associated with on-the-job death rates (Viscusi 2004; Viscusi 2018). Stated preference methods typically employ survey techniques, including contingent valuation surveys and choice experiments, to assess WTP for the outcome of concern (Robinson and Hammitt 2013). Stated preference methods have been frequently used for the valuation of reductions in risk of mortality (Hammitt and Graham 1999; Hammitt and Zhou 2006). Relatively few revealed preference or stated preference studies have attempted to quantify WTP for reduced risks of nonfatal outcomes. Challenges include isolating the effect of morbidity from other attributes and heterogeneity in assessing the implications of morbidity. That is particularly the case for morbidity risk reductions in children evaluated by parents (von Stackelberg and Hammitt 2009). WTP theoretically estimates all the costs associated with the disease including medical and indirect costs that are parts of cost-of-illness estimates, as well as intangible costs, such as pain and suffering and emotional loss.

We searched for Willingness to Pay for IQ on Google Scholar and Scopus with keywords such as "WTP", "Willingness to Pay", "IQ", "contingent valuation", "revealed preference", "stated preference". Given the limited number of studies we identified, we also did general Google search for reports or working papers on this topic.

Case study

To demonstrate how these benefit estimates can be applied in a benefit-cost analysis, we did a break-even analysis. For a house that had LSL replacement, we estimated how many children need to live in the house and benefit from the lead exposure reduction for the benefit to be equal to the cost. The cost to replace a LSL depends on the length of the LSL and other site-specific variables. To estimate the cost, we used publicly available information of several existing actions. In Lansing, Michigan, the average cost was reported to be $3,560 per LSL and in Milwaukee the cost was estimated to be up to $7,000 per LSL (Health Impact Project 2017). New York State Department of Health estimated the replacement cost could be between $5,000 and $10,000 per

LSL (New York State Department of Health 2018). For the case study we assumed $7,000 as the average cost of LSL replacement.

We estimated IQ increase and the corresponding health benefit as a result of reduced lead exposure for children as:

$$Health\ Benefit = \Delta C \times \left(\frac{\Delta BLL}{\Delta C}\right) \times \left(\frac{\Delta IQ}{\Delta BLL}\right) \times \left(\frac{\Delta V}{\Delta IQ}\right)$$

ΔC is reduction in lead concentration (in ppb) in drinking water after LSL replacement. ΔBLL/ΔC is reduction in BLL (in micrograms per deciliter or μg/dL) per unit reduction in lead concentration in drinking water. $\Delta IQ/\Delta BLL$ is increase in IQ per 1 μg/dL reduction in BLL. $\Delta V/\Delta IQ$ is increase in monetary value per 1 IQ point increase. To value the health benefit, we assigned monetary values to the increase in IQ based on human capital and WTP approaches. We then compared the benefits with costs, to estimate the number of children needed to live in a house with LSL replacement, in order for the action to break-even.

The Lead and Copper Rule (LCR) established an action level of 15 ppb for lead (EPA 2019b). If lead concentrations exceed 15 ppb in more than 10 percent of customer taps sampled, the system must undertake actions to control corrosion. For this case study, we assume LSL replacement targeted houses with lead level at the action level, and the lead concentration was 15 ppb before LSL replacement. We conservatively assumed that LSL could reduce drinking water lead level to 2 ppb, because of remaining lead plumbing fixtures and solder in homes (Health Impact Project 2017). We multiplied the 13 ppb (15 minus 2 ppb) reduction in lead level following LSL replacement by an assumed 0.042 μg/dL change in BLL per 1 ppb difference in water lead, based on EPA's Integrated Exposure Uptake and Biokinetic (IEUBK) model (Health Impact Project 2017).

To estimate the change in IQ as a result of reduction in BLL, we reviewed epidemiology studies. Lanphear et al. found the relationship of IQ with children's BLL to be nonlinear, with greater change in IQ across lower as compared to higher BLLs. The log-linear model estimated an increase in a child's concurrent blood lead level (BLL) from 2.4 μg per deciliter (μg/dL) to 10 μg/dL to be associated with a decrease of approximately 3.8 IQ points

(Lanphear et al. 2005). Canfield et al. estimated that IQ declined by 7.4 points as lifetime average blood lead concentrations increase from 1 to 10 μg/dL (Canfield et al. 2003). Using a linear model, Canfield et al. estimated that for children whose maximal lead concentrations remained below 10 μg/dL, the linear reduction in IQ was 1.37 points per 1 μg/dL increase in BLL with 95% confidence interval (CI) of 0.17 to 2.56. We assumed a linear slope of 1 IQ point decrease per 1 μg/dL increase in BLL, which was used by California Environmental Protection Agency (Office of Environmental Health Hazard Assessment 2009).

In addition, we conducted a sensitivity analysis to understand the range of the potential outcomes. For cost, we assumed a uniform distribution between $3,560 and $10,000 per LSL, based on cost information of several existing actions. For lead concentration before LSL replacement, we assumed a uniform distribution of 5 to 25 ppb. For lead concentration after LSL replacement, we assumed a uniform distribution of 0 to 4 ppb. 0 ppb is the ideal outcome when drinking water is free of lead. For change in BLL per 1 ppb difference in water lead concentration, we assumed it can vary by a factor of 2 from the value in the base case. We used a triangular distribution with minimum, mode and maximum of 0.021, 0.042 and 0.084 μg/dL change in BLL per 1 ppb difference in water lead, respectively. For change in IQ as a result of reduction in BLL, we assumed a uniform distribution of 0.5 to 1.5 IQ point decrease per 1 μg/dL increase in BLL, based on available epidemiology study estimates for low BLLs.

Results

Human capital approach estimate review

Schwartz developed a model to calculate the value of an IQ point as part of a cost-benefit analysis of removing lead from gasoline (Levin 1986), which was subsequently adapted in a 1991 Strategic Plan for the Elimination of Childhood Lead Poisoning and eventually published (Schwartz 1994). Schwartz modeled the direct and indirect effects of cognitive ability on hourly wages and annual earnings, with annual earnings modeled as the product of hourly wages and annual hours of paid employment. Based on economic studies from the 1970s, Schwartz assumed a direct effect per IQ point of 0.5% on hourly wages and an indirect effect of 0.79% in hourly earnings per IQ point mediated by years of schooling and the impact of schooling on wages. Last, Schwartz modeled the effect of IQ on high school graduation and the effect of graduation on annual hours and earnings, resulting in additional difference of 0.47% in annual earnings per IQ point loss, for a total difference of 1.76% in annual earnings per IQ point.

The next year, Salkever reported higher estimates of the impact of 1 IQ point on annual earnings on the basis of an analysis of data from the 1979 National Longitudinal Study of Youth (NLSY79) cohort, who were tested at ages 14-23 in 1980 with the Armed Services Vocational Aptitude Battery (ASVAB) (Salkever 1995). Salkever used the Armed Forces Qualifying Test (AFQT) scores derived from the ASVAB, standardized on the same 100 point scale as IQ, as a proxy for IQ to predict earnings from the 1990 wave, when respondents were ages 25 to 33. The direct effect of the equivalent of 1 IQ point on hourly earnings was estimated as 1.24% for males and 1.40% for females, more than twice as high as the consensus estimates from the economics literature cited by Schwartz. The indirect effects were also estimated to be much larger, especially for females, with schooling having more than twice the positive effect on female hourly earnings and almost eight times greater impact on labor force participation for females than for males. The total effect of 1 point in ability on annual earnings was modeled as 2.09% for males and 3.63% for females, with a weighted average of 2.37% for both genders.

The Schwartz and Salkever estimates of the proportional effect of IQ on annual earnings have been widely used in environmental health economic assessments (Griffiths et al. 2007; Landrigan et al. 2002; Muir and Zegarac 2001; Trasande et al. 2005; Trasande and Liu 2011). For example, Grosse et al. (2002) applied a 2.0% base-case estimate of the slope of earnings per IQ point (average of 1.76% and 2.37% estimates from Schwartz and Salkever) to a present value of lifetime earnings of $723,300 in 2000 dollars calculated using a 3% discount rate and estimated the value of 1 IQ point of $14,500, (range $12,700–$17,200). Trasande and Liu (2011) similarly assumed 2.0% increase in earnings for each 1 IQ point gain in ability but assumed lifetime output of $1.3 million in 2007 dollars (sum of market and non-market productivity), yielding a value of an IQ point of almost $26,000.

Two studies adjusted the $14,500 base-case dollar value from Grosse et al. for inflation (Gould 2009; Nevin et al. 2008), and other studies took the roughly $18,000 estimate from Gould (2009) in 2006 dollars without further adjustments (Bartlett and Trasande 2013; Bellanger et al. 2013; Pichery et al. 2012).

Some skeptics have argued that the IQ-earnings estimates of Schwartz and Salkever used by researchers are overstated. For example, Gayer and Hahn argued that the plausible range of the effect of 1 IQ point on (hourly) earnings was between 0.4% and 1.1% (Gayer and Hahn 2006). Similarly, Rice et al. cited a finding that a 1 point increase in an AFQT-based proxy for IQ in NLSY79 data was associated with 0.9% higher hourly earnings for males and 1.2% higher hourly earnings for females (Rice et al. 2010). However, since cognitive ability is positively associated with labor force participation, employment, and annual hours of paid work, it is the association of IQ with annual earnings, not hourly earnings, that is relevant (Salkever 2014).

Another critique of published IQ-earnings associations using NLSY data is that AFQT scores are a biased proxy for IQ scores (Grosse 2007; Grosse 2014). AFQT scores measure mastery of factual knowledge, such as trigonometry, unlike IQ tests which measure fluid intelligence (Heckman 1995), and are also highly correlated with family background (Currie and Thomas 1999). Since the test scores are a function of age and schooling attainment, economists have typically adjusted ASVAB or AFQT scores for age and years of schooling attained at the time tests were taken (Blackburn and Neumark 1993; Murnane et al. 2001; Neal and Johnson 1996; Zagorsky 2007), although Salkever did not. Salkever also did not adjust for confounding by family characteristics associated with both adolescent test scores and later economic success, which has been argued to result in biased estimates of the association of ability and earnings (Greene 2013; Wooldridge 2015).

Direct estimates of the association of cognitive ability with annual earnings are consistently lower than the estimates modeled by either Salkever or Schwartz for comparable age groups. A study that used NLSY79 data for respondents during 2014 (at ages 49 to 57) and used age-adjusted AFQT scores as a proxy for IQ found that a 1 point difference was associated with 1.0% higher annual income after adjustment for outliers (Zagorsky 2007). A second study also used NLSY79 data for the cohort followed to 2014 to assess the long-term association of adolescent cognitive performance with earnings, although the earlier study by Zagorsky was not referenced (Lin et al. 2018). Lin, Lutter, and Ruhm used the 2006 renormed AFQT scores and controlled for numerous potential confounders. They reported that in the most complete model, which included control for non-cognitive ability, a 0.1 standard deviation in ability (i.e., roughly equivalent to 1.5 IQ points) was associated with adjusted differences in earnings of 2.0% at age 30, 2.7% at age 40, and 3.3% at age 50 (1.3%, 1.8%, and 2.2% per 1 point difference). The estimate of the association of ability with annual earnings at age 30 was roughly one-half the magnitude of the earlier estimate by Salkever for the same age group.

One analysis used data from the Wisconsin Longitudinal Study of Social and Psychological Factors in Aspiration and Attainment (WLS), which followed a cohort of U.S. high school graduates in Wisconsin in 1957, all of whom had IQ scores assessed. Zax and Rees regressed annual earnings for males at ages 35 and 53 years on adolescent IQ scores (Zax and Rees 2002). In regressions controlling for family characteristics, 1 IQ point was associated with 0.58% higher earnings at age 35 and 1.39% higher earnings at age 53 (Zax and Rees 2002). The larger coefficient at age 53 reflects the phenomenon of an increasing return to cognitive ability with age, as earnings plateau at younger ages for those with lower ability and education, a trajectory similar to that reported in NLSY79 data (Lin et al. 2018).

Although a systematic review endorsed the Zax and Rees adjusted estimate of a 1% increase in annual earnings per IQ point as the best available estimate in a high-income country (Monahan et al. 2015), that estimate may be biased downwards. First, the sample analyzed by Zax and Rees excluded non-graduates and females and had few nonwhite participants, groups with higher returns to cognitive ability (Lin et al. 2018; Salkever 2014). In general, cognitive ability in childhood is reported to be more strongly correlated with ultimate educational attainments in more disadvantaged populations with greater disparities in access to education (Peet et al. 2015). Second, controlling for parental education and income may over control for the effect of IQ on earnings due to shared genes of offspring and parents (Ganzach 2011; Grosse 2007). In any case, an increase in the skill premium in U.S. labor markets in recent decades suggests a greater return to cognitive ability today than for persons born circa 1940. In particular, earnings growth has been most rapid for individuals with higher education and cognitive ability (Bowles et al. 2001; Cawley et al. 2001). However, a comparative analysis of data from the NLSY79 and NLS 1997 cohorts found similar associations of cognitive ability and earnings up to age 30 in two cohorts born two decades apart (Lin et al. 2018).

In summary, it is challenging to calculate a single point estimate of the dollar value of an IQ point from the human capital perspective. First, the proportional increase in real earnings with increased cognitive ability is uncertain, although it may be in the range of 1.3% to 2.2% per IQ point, varying over the life cycle. Higher returns to cognitive ability at age 50 are more heavily discounted when assessed as a present value in early childhood. Second, the present value of real (inflation-adjusted) gross earnings in early childhood is uncertain. Recently published estimates based on 2016 data indicate the present value of expected gross earnings at birth of $934,583 using a 3% discount rate and assuming 1% annual growth in future real earnings and $758,954 assuming 0.5% annual growth in real earnings (Grosse et al. 2019a). Adjusted for inflation, those present value estimates are roughly $980,000 and $800,000, respectively. If one assumes that the present value of gross earnings is increased by 1.5-1.8% per IQ point, that implies a range of $12,000 to $17,500 per IQ point in 2018 dollars. Those estimates place no economic value on cognitive ability applied to childrearing or other unpaid household services; if one were to assume a proportionate increase in non-market productivity, the return to IQ could be roughly 50% greater (Grosse et al. 2019a).

Willingness to Pay estimates

We found one stated preference study in the peer reviewed literature that directly reported WTP for decreased risk of IQ reduction (von Stackelberg and Hammitt 2009). The study reported the results of several contingent valuation (CV) surveys to elicit WTP values from the general public for risk reductions associated with decreases in PCB exposure in the environment. One of the health effects the survey asked respondents to value is a twenty-in-one-hundred chance of a 6-point reduction in IQ due to the PCB exposure. WTP per IQ point was estimated to be $466 with the 95% confidence interval of ($380, $520) (2005 dollar). The study also reported that WTP is sensitive to the probability of risk reduction with WTP proportional to risk reduction. This means that respondents who were offered a larger risk reduction had a greater WTP. This suggests that they adequately appreciate the magnitude of the risk reduction presented to them (Corso et al. 2001; Hammitt and Graham 1999).

A working paper by Lutter estimated parents' WTP between $1,100 and $1,900 per IQ point gained (1997 dollars) (Lutter 2000). This was based on an earlier revealed preference study by Agee and Crocker, which studied parental decisions to use chelation therapy, a medical procedure that accelerates the natural excretion of lead from children's bodies (Agee and Crocker 1996). Agee and Crocker reported average parental WTP for a 1% reduction in child lead burden to be $16 (1980 dollars). Lutter converted this to an average WTP of $31 (1997 dollars) by adjusting for inflation. Then, Lutter divided $31 by 0.15 parts per million (ppm), which is 1% of the average dentine lead level in the Agee and Crocker sample and derived an estimate of $210 (1997 dollars) for a reduction of lead in teeth of 1 ppm. Based on the change in IQ for a unit change in dentine lead in the literature, Lutter estimated the WTP per IQ is $1,100 (1997 dollars) (Lutter 2000). Alternatively, Lutter combined the relationship between BLL and dentine lead with an average decrease of 0.25 IQ points per μg/dL of BLL for children with BLL between 10 and 20 μg/dL (Schwartz 1994), and estimated WTP per IQ as $1,900 (Lutter 2000).

In deriving WTP per IQ, Lutter assumed that reduction in dentine and blood lead through chelation therapy would result in higher IQ. However, a randomized trial found that treatment with succimer (an oral lead chelator) lowered blood lead levels but did not improve scores on tests of cognition, behavior, or neuropsychological function in children with BLLs below 45 μg/dL (Rogan et al. 2001). Differences in BLL between treatment and placebo groups were small and no longer present one year after the initiation of treatment or placebo.

Case study

By combining reduction in lead level in drinking water, reduction in BLL and the corresponding increase in IQ, we estimate that the increase in cognitive ability for a child living in a home with LSL replaced is equal to 13 × 0.042 × 1, which is 0.55 IQ point. To value that health benefit, we applied the values of an IQ point ranging from $12,000 to $17,500 from the human capital approach; the expected monetary benefit per child ranges from $6,600 to $9,600. Since the average cost estimate is $7,000 per LSL replacement, if more than one child benefits from the LSL replacement in a house, the benefit will outweigh the cost. If we apply the stated preference WTP estimate of $600 per IQ point (2018 dollars), there would need to be more than 21 children per house with LSL replaced for the benefit to outweigh the cost. If we apply the WTP estimate of $3,000 (2018 dollars) (based on $1,900 WTP estimate in 1997 dollars from Lutter study), there needs to be more than 4 children per house to break-even. Note that LSL replacement will not only benefit current residents of the house, it will also benefit children who will live in the house in the future. In this case study, we did not discount future benefits. Additional analyses could incorporate assumptions regarding the expected life span of the house and benefits for future child residents in the house.

In the sensitivity analysis, the 95% confidence interval (CI) for IQ increase after LSL replacement range from 0.14 to 1.43. To value the health benefit using human capital approach, we assumed a uniform distribution of $12,000 to $17,500 per IQ point. The average number of children needed to breakeven is 1.2 with 95% CI of 0.3 to 3.4. To value the health benefit using WTP approach, we assumed a uniform distribution of $600 to $3,000 per IQ point. The average number of children needed to breakeven is 12 with 95% CI of 2 to 36.

Discussion and Conclusion

Human capital estimates of the association of cognitive ability and earnings have multiple challenges. First, association does not prove causation. Individuals with higher IQ may have higher earnings for multiple reasons, including confounding by social advantages. There may be reverse causation if individuals who enjoy higher educational and occupational attainments have higher test scores independent of cognitive ability as measured in childhood. Second, the causal pathway from IQ to earnings is complex. Third, IQ test scores are rarely available in economic data sets with information on individual earnings. Instead, achievement test scores are used as a proxy for general ability, which may lead to under or overestimates.

In the case study, except for the monetary value per IQ, values of the other parameters are generally within a factor of 2 depending on the assumptions made. In comparison, the uncertainty in the monetary value per IQ, due to the different approaches applied (e.g., $17,500 vs $600 per IQ point), is one order of magnitude higher than the rest of the parameters. The large discrepancy in economic value per IQ using human capital approach and WTP approaches could be due to several reasons. They provide measurements from different perspectives. The human capital approach provides estimates from the societal perspective of impacts on future economic productivity, typically based on projected gross (pre-tax) earnings. It presumes that higher future earnings represent higher productive potential of a child with higher IQ. WTP estimates are based on preferences from the parental perspective and the amount of money is based on their after-tax income. The implicit assumption is that parental preferences represent child preferences. Also, it is not clear what the parental WTP is measuring. The WTP study pointed out that it is highly unlikely that respondents are thinking about the implications of IQ on future earnings or on future health states (von Stackelberg and Hammitt 2009). Among respondents who answered "Yes" to at least one offer bid, the authors found that over 92% rated altruism (i.e., I am worried about the potential risk to unborn babies generally) and general support for a cleanup (i.e., I support a cleanup no matter what the risk might be) as somewhat to extremely important, In comparison, 59% of these respondents considered potential risk to their own unborn children as somewhat to extremely important (von Stackelberg and Hammitt 2009).

We hypothesize that the parental WTP estimates reported by von Stackelberg and Hammitt measure the intangible benefits to parents, e.g., the emotional gain from knowing their or other children will not suffer from the adverse health effect of PCB pollution. Given the differences between the human capital and WTP approaches, we consider these two estimates to be complementary and suggest that they be combined to estimate the total economic value per IQ point. The implied economic value ranges from $12,600 to $19,400 per IQ point in 2018 dollars when human capital and WTP estimates are combined.

The sum of human capital and WTP estimates of the value of an IQ point is an incomplete, hence conservative, measure of the economic impact of lead exposure. First, if cognitive ability positively affects non-market productivity, as seems likely, the estimates of the economic benefits of increased cognitive ability based only on earnings data are underestimates. Second, in addition to lost productivity, lead exposure has been associated with higher costs for special education and involvement in the criminal justice system (Nevin 2007). For example, Schwartz (1994) reported that 20% of children with BLL > 25 µg/dL needed special education for an average of 3 years (Schwartz 1994). Third, for children with BLL > 10 µg/dL, there could be additional health care costs. For example, for children with BLL ranging from 10 to 20, 20 to 45, 45 to 70, and ≥ 70 µg/dL, the testing and treatment cost per child was estimated to $70, $1000, $1,300, and $3,400, respectively (Gould 2009). However, few U.S. children currently have highly elevated BLLs, with < 0.2% of children under age 6 years in the Unites States having BLL of ≥10 µg/dL during 2015–2016 (CDC 2019b). Therefore, in this case study we focused on estimates of productivity and intangible costs using the human capital and WTP approaches.

Adverse health effects of lead have been observed in every organ system. The most extensively studied health outcomes due to lead exposure are neurological, renal, cardiovascular, hematological, immunological, reproductive, and developmental effects. This study focused on IQ reduction in children, as cognitive deficits in children are the best substantiated effects of low-level lead concentrations (≤5 µg/dL) (ATSDR 2019). Health benefit estimates in the case study are likely an underestimate since we focused on cognitive effects alone in young children. Health benefits to other body systems and benefits to adults and older children were not included.

In conclusion, the largest source of uncertainty in estimates of the health benefits of reducing childhood lead exposure is the monetary value of IQ. We think the large discrepancy in the value per IQ estimates using human capital and WTP approaches is due in large part to the different perspectives (e.g., societal vs. parental) and the target for measurement (e.g., using future income as proxy for children's utility vs. using the intangible benefits of higher IQ from parental perspective as proxy). Given these differences, estimates using these two approaches can also complement each other. Additional revealed preference and stated preference studies on this topic could help fill in the gap in knowledge.

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