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ScienceDirect
Environmental Research 104 (2007) 315–336
Environmental Research
www.elsevier.com/locate/envres

Understanding international crime trends: The legacy of preschool lead exposure

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Received 12 August 2006; received in revised form 20 February 2007; accepted 23 February 2007
Available online 23 April 2007

Abstract

This study shows a very strong association between preschool blood lead and subsequent crime rate trends over several decades in the USA, Britain, Canada, France, Australia, Finland, Italy, West Germany, and New Zealand. The relationship is characterized by best-fit lags (highest R^2 and *t*-value for blood lead) consistent with neurobehavioral damage in the first year of life and the peak age of offending for index crime, burglary, and violent crime. The impact of blood lead is also evident in age-specific arrest and incarceration trends. Regression analysis of average 1985–1994 murder rates across USA cities suggests that murder could be especially associated with more severe cases of childhood lead poisoning.

Keywords: Lead poisoning; Crime; IQ; Behavior; Violence

1. Introduction

Crime trends can be related to demographic, cultural, economic, and law enforcement trends, but the sharp 1990s USA crime decline was not anticipated by such theories. Fox (1996) forecasted a 1995–2005 increase in teen murderers due to a rising population of teens, and especially black teens. Those demographic trends were overwhelmed by a 77% fall in the juvenile murder arrest rate from 1993–2003, led by an 83% decline for black youths (Office of Juvenile Justice and Delinquency Prevention, 2004). DiIulio (1996) warned juvenile crime was "getting worse" due to children growing up around "criminal adults" in "fatherless … jobless settings". Juvenile arrests then plummeted as adult arrest rates changed little, with the percent of children raised by single parents at record highs, and fell further as unemployment rose after 2000. Levitt (2004) reviews evidence that unemployment has a "statistically significant but substantively small relationship" with property crime and no effect on violence, but says the 1990s crime decline can be explained by rising police per capita and incarceration rates and the early-1970s abortion of "unwanted" children, presumed more likely to offend (Donohue and Levitt, 2001). Levitt admits this model cannot explain 1973–1991 trends, when crime and incarceration rates surged as police per capita changed little (Harrison, 2000; Reaves, 2003; Bureau of Justice Statistics, 2006). International crime trends are even more vexing (Ferrington et al., 2004). Britain legalized abortion before the USA, but violent crime rose in Britain and across Europe and Oceana in the 1990s despite rising incarceration rates, rising or unchanged police per capita, and declines in the age 15–19 share of the population (Barclay and Tavares, 2003; US census, 2004).

Criminal offending is also associated with brain damage (Raine et al., 1998), and the use of lead in paint and gasoline caused global neurotoxin exposure. Elevated maternal and preschool blood lead can impair formative brain growth, as "incomplete development of the blood–brain barrier in fetuses and in very young children (up to 36 months of age) increases the risk of lead's entry into the developing nervous system, which can result in prolonged or permanent neurobehavioral disorders" (Agency for Toxic Substances and Disease Registry, 2000). Preschool blood lead over 70 μg/dL (micrograms of lead per deciliter

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0013-9351/$ - see front matter
doi:10.1016/j.envres.2007.02.008

of blood) can cause seizures and death, blood lead over 10 μg/dL is harmful to learning and behavior and there is no lower blood lead threshold for IQ losses (US Centers for Disease Control and Prevention, 1991; Schwartz, 1994; Canfield et al., 2003). The half-life of lead in blood is 30 days, but preschool blood lead often changes slowly due to continuing exposure, and that lead burden accumulates in teeth and bones (World Health Organization, 1995). Needleman et al. (2003) found youths with high bone lead are twice as likely to be delinquent, after controlling for confounders. Other studies also link preschool lead exposure to aggressive and delinquent adolescent behavior and later criminal violence (Denno, 1990; Needleman et al., 1996; Dietrich et al., 2001).

Stretesky and Lynch (2001) found USA counties with high 1990 air lead, mostly from industrial emissions, had 1989–1991 murder rates four times higher than counties with low air lead, after controlling for nine air pollutants and six sociological factors. This study likely reflects 1970s additive preschool lead exposure, because if murder were much affected by contemporaneous air lead then the homicide rate would have fallen as gasoline lead and air lead fell over 70% from 1975–1984 (US Environmental Protection Agency, 1986). Most 1990 lead-emitting facilities were in operation for decades, in areas with older housing and some traffic, so 1989–1991 murder rates likely reflected higher 1970s blood lead where children had additive exposure to lead in paint and gasoline and industrial emissions. Nevin (2000) found 1941–1975 gasoline lead use explained 90% of the 1964–1998 variation in USA violent crime. The best statistical-fit lag of 23-years is consistent with neural damage in infancy and peak ages of violent offending. Nevin showed a best-fit lag of 18 years for gasoline lead versus 1960–1998 murders, and 21 years for per capita paint lead use versus 1900–1959 murders. The difference in best-fit murder lags is consistent with when paint and gas lead most affected preschool lead exposure. Gas lead settled over a few weeks or months, and heavily leaded circa-1900 lead paint deteriorated via "chalking" after 3 years (Schwartz and Pitcher, 1989; van Alphen, 1998).

1.1. *Lead exposure pathways and population blood lead trends*

Elevated blood lead can be due to lead paint chip ingestion, inhaled air lead, and other pathways, but paint and gasoline had especially pervasive effects due to lead contaminated dust ingested via normal hand-to-mouth activity as children crawl. Average daily lead ingested by 2-year-olds exposed to dust contaminated by interior lead paint is similar to the average for 2-year-olds exposed to dust contaminated by settled city air lead, and average 2-year-old lead ingestion via dust is many times average ingestion via inhaled air lead, dietary lead (from air lead settled on crops and/or lead solder in food and beverage cans), or other pathways (US Environmental Protection Agency, 1986).

Lead used in paint accounted for almost a third of total USA lead output from 1900–1914, when the USA produced over 40% of world lead output (Nevin, 2000; US Geological Survey, 2006). The high USA per capita use of lead in early-1900s paint caused more severe USA lead paint hazards throughout the 20th Century. The lead share of USA paint pigments fell from near 100% in 1900 to 35% in the mid-1930s (Meyer and Mitchell, 1943), but the USA did not ban residential lead paint until 1978. Pre-1940 and 1940–1959 homes each accounted for about a third of USA homes in the early-1980s, and about 80% of pre-1940 and 46% of 1940–1959 homes still had some interior lead paint in 1999 (US Census, 1977–2003; Jacobs et al., 2002). Since the 1980s USA phase out of lead in gasoline, preschool blood lead prevalence over 10 μg/dL has tracked USA trends in the prevalence of housing with dust hazards caused by interior lead paint (Jacobs and Nevin, 2006). Trends in preschool blood lead prevalence over 10 μg/dL are especially affected by widespread exposure to lead dust hazards, but paint chip ingestion is often a factor in severe lead poisoning. A 1989–1990 study found that children with X-ray evidence of recent paint chip ingestion had average blood lead of 63 μg/dL (McElvaine et al., 1992).

Per capita use of lead in gasoline surged in the USA after World War II, and rose at a slower rate in nations with lower per capita gasoline consumption. Lead emissions from urban traffic caused greater lead exposure for city children because 10% of lead emissions settled within 100 m of the road and 55% within 20 km, however atmospheric emissions also affected blood lead in areas with little traffic (Organization for Economic Co-Operation and Development, 1993). National trends in average blood lead and the use of lead in gasoline were highly correlated, with median R^2 of 0.94 in Greece, Spain, South Africa, Venezuela, Belgium, Sweden, Mexico, Finland, Canada, New Zealand, Italy, Switzerland, Britain and the USA (Thomas et al., 1999). Children exposed to lead in paint and gasoline had a greater risk of elevated blood lead because lead ingestion is additive, but average blood lead closely tracked gasoline lead use due to slow changes in lead paint exposure after the 1930s. Lead exposure also spanned a wide range due to gas lead fallout related to city size and road proximity. USA cities with population over a million had early-1960s ambient air lead twice that in cities of 250,000 to a million, which had air lead 40% higher than cities of 100,000–250,000. Air lead beside a heavily trafficked Cincinnati street (2150 cars/h or about 50,000 cars/day) was 15 times the city's ambient air lead (US Public Health Service, 1966, 1965). Severe lead exposure was an unrecognized consequence of locating public housing beside highways. For example, Chicago's long narrow Robert Taylor Homes project that opened in 1962 was all within about 400 m of 1963 Dan Ryan expressway traffic of 150,000 vehicles/day (American Highway Users Alliance, 2004).

Many children had additive 1950–1970 exposure to city air lead and severely deteriorated lead paint in circa-1900 slum housing. “In the 1960s many inner city hospitals had large numbers of comatose and convulsing children with lead poisoning, with fatality rates of 5–28%” (Jackson, 1998). There was extensive slum demolition as urban renewal projects in execution rose seven-fold from 1956–1966, but slum clearance slowed in the late-1960s (US Department of Housing and Urban Development, 1971). Public housing collocated with highways on slum clearance land also caused severe air lead exposure as per capita gas lead rose 50% from 1962 to 1970. City blood lead screening in 1970 showed about 25% of young children tested had blood lead over 40 μg/dL. Gilsinn (1972) found 95% of 1970 Census tract variation in children over 40 μg/dL was explained by the tract population under age seven and prevalence of deteriorated or dilapidated housing, but New York City children over 40 μg/dL relative to substandard housing prevalence was 20% higher than smaller cities, consistent with higher New York City air lead.

The 1976–1980 National Health and Nutrition Examination Survey (NHANES) revealed average USA preschool blood lead of 15 μg/dL, and the 1988–1991 NHANES showed blood lead fell sharply with the leaded gas phase-out (Pirkle et al., 1994). Per capita use of lead in gasoline peaked later in most nations but per capita paint lead use peaked earlier, and lead paint hazards raised USA elevated blood lead risks. Australia 1995 average preschool blood lead was 50% above the 1990 USA average, but 9% of 1990 USA children versus 7% of 1995 Australia children were over 10 μg/dL (Pirkle et al., 1994; Australian Institute of Health and Welfare, 1996). Canadian and USA late-1970s average blood lead were similar but 4% of Canadian versus 18% of white and 52% of black USA children were over 20 μg/dL (Royal Society of Canada, 1986). In 1960, blacks occupied 15% of central city households and 56% of substandard central city housing, and the percent of all central city blacks in substandard housing was 25% in 1960 and 16% in 1966 (Kristof, 1968; Koebel, 1996). Per capita gas lead fell from 1956–1962 but hit new highs from 1966–1974, when 62% of blacks under age six lived in central cities, versus 24% of white children, with blacks concentrated in older housing (US Census, 1960–90). Average blood lead for black 2-year-olds in Chicago and New York City fell by about 30% from 1970–1978, but the 1976–1980 USA average for black children ages 6–36 months was still 50% above the white average, and the black prevalence over 40 μg/dL was 800% higher (Agency for Toxic Substances and Disease Registry, 1988).

1.2. Brain growth, lead exposure, IQ, and behavior

Critical growth spurts in gray and white matter occur before age two, when elevated maternal and preschool blood lead cause many neurological effects that establish a basis for impairments in IQ, learning, and behavior (Banks et al., 1997; Lidsky and Schneider, 2003; Matsuzawa et al., 2001). Outcomes are also affected by exposure severity, duration, and timing, and interactions with diet and socioeconomic status (Bellinger, 2004). Behavior problems could be an indirect effect of IQ or the direct effect of brain damage impairing impulse control (Needleman et al., 2003). Gottfredson (1998) observes that youths with IQ of 75–90 are seven times more likely to be incarcerated than those with IQ of 110–125, and states: “no other trait or circumstance yet studied is so deeply implicated in the nexus of bad social outcomes” as low IQ. This perspective, however, does not address how IQ that is stable after childhood (Neisser et al., 1996) might relate to an age 15–17 property crime arrest rate that averaged nine times the over-25 rate from 1970–2003. (Bureau of Justice Statistics, 2004). A different perspective is provided by magnetic resonance imaging studies that reveal a second gray matter growth surge just before puberty, predominating in the frontal lobe, “the seat of ‘executive functions’—planning, impulse control and reasoning” (National Institute of Mental Health, 2001). Sowell et al. (1999) reports scans at ages 12–16 and 23–30 showing a large frontal lobe difference in myelin, which progressively insulates and thickens white matter connections between neuron cell bodies. Bartzokis et al. (2001) reports frontal lobe white matter growth to age 50, as gray matter declines, and explains: “What keeps growing is the myelin … [which] affects the speed of the signals that travel from neuron to neuron … [and] allows your brain to work in concert; you’re not as prone to impulse” (Foster, 2001). Bartzokis et al. (2001) attributes impulsive teen behavior to incomplete myelination, and links myelin disruption to developmental disorders.

Developmental effects of lead exposure include the destruction of myelin sheaths and decreased activity of an enzyme integral to myelin synthesis (Lidsky and Schneider, 2003). More generally, Silbergeld (1992) observed that lead exposure during critical periods of vulnerability can cause permanent brain damage, but neurotransmission effects could be reversible absent continuous exposure. Gray matter damage causing permanent IQ loss, and neurotransmission damage that affects behavior, could cause an IQ–crime correlation due to separate lead effects. Age-related offending could be linked to incomplete myelination among teens with or without preschool lead exposure, but criminal behavior could be more common and severe with impaired and/or delayed myelination or other neurotransmission damage. White matter growth to age 50 suggests that lead-induced neurotransmission disruption could also affect behavior well beyond adolescence, especially if more continuous exposure causes irreversible effects.

In a Supreme Court brief opposing juvenile executions, the American Psychological Association (2004) argued that the adolescent brain “has not reached adult maturity, particularly in the frontal lobes, which control … decision-making”. That brief included a graph showing violent offenses “build steeply to 18, before starting to drop off” as offending is often “moderated or eliminated by the individual in adulthood''. That same graph also reveals age-specific arrest rate shifts that track lead exposure and violent crime trends [Fig. 1]. Youths ages 16–22 in 1994 were all born before the early-1980s fall in gasoline lead, and the age-16 arrest rate was 29% higher than the age-22 rate in 1994, consistent with criminal behavior being moderated by changes in frontal lobe development of adolescents and young adults. The 22-year-olds in 2001 were also born before the early-1980s decline in lead exposure, but the 16-year-olds were born in the mid-1980s, and the 2001 age-16 arrest rate was 12% *lower* than the age-22 arrest rate.

This study examines international trends in preschool blood lead, crime rates, and age-specific arrests rates, to test whether the relationship between lead exposure, arrest, and crime trends in Fig. 1 is evident across many crime categories and across nations with divergent preschool blood lead and crime rate trends. International, racial, and city differences in severe lead poisoning prevalence are also compared with subsequent contrasts in murder rates and juvenile violence, with the expectation that severe preschool lead poisoning could be linked to more violent offending and especially to murder rates.

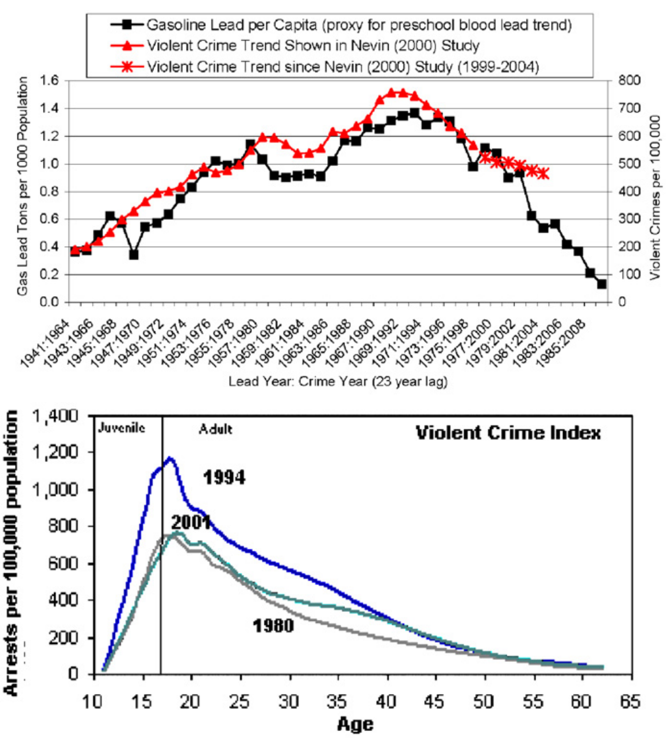

Fig. 1. USA violent Crime and Lead Exposure Trends and Age-Specific Violent Crime Arrest Rate Shifts. Legend: Nevin (2000) found that 1941–1975 gasoline lead use explained 90% of the 1964–1998 variation in USA violent crime, where the 23-year lag is consistent with neurobehavioral effects of lead exposure in infancy and the typical age of violent offenders. Age-specific violent crime arrest rates (Office of Juvenile Justice and Delinquency Prevention, 2004) also reveal that peak offending shifted to older ages by 2001, as the 1990s violent crime decline was associated with an especially sharp decline among juveniles born after the early-1980s decline in gas lead.

2. Methods

2.1. Arrest rate and incarceration trends

USA index crimes include property crimes (burglary and theft) and the violent crimes of murder, rape, robbery, and aggravated assault (causing injury or with a lethal weapon). British indictable offenses include USA index crimes plus threats, simple assaults without injury, and petty thefts below a USA monetary threshold for larceny. The following USA and British data are examined to highlight peak offending ages and temporal shifts in age-specific offending:

1. British age-specific ''caution and conviction'' rates (similar to USA arrest rates) for indictable offenses in 1958 versus 1997 (Taylor, 1999).
2. California Department of Justice (2005) 1960–2004 juvenile and adult index crime arrest rates (age 10–17 arrests per 100,000 ages 10–17, and adult arrests per 100,000 ages 18–69).
3. USA 1970–2003 age-specific property crime arrest rates (Bureau of Justice Statistics, 2004).
4. USA 1980–2001 age-specific arrest rates for property and violent crimes, and 1980–2003 juvenile arrests by race (Office of Juvenile Justice and Delinquency Prevention, 2004).
5. USA incarceration by age, and recidivism trends (Harrison and Beck, 2005; Beck and Harrison, 2001; Langan and Levin, 2002; Bureau of Justice Statistics, 1993, 2001).

2.2. Preschool blood lead and international crime trends

Regression analyses compare international crime rate trends with estimated preschool blood lead trends. Fig. 2 shows USA 1936–1999 preschool blood lead estimates anchored by NHANES data, and estimates for all ages for comparison with earlier blood lead data (Thomas et al., 1999; Pirkle et al., 1994; US Centers for Disease Control and Prevention, 1997, 2000; Organization for Economic Co-Operation and Development, 1993). These estimates reflect 1980–1988 air lead, 1946–1976 refinery lead use, and 1936–1946 road gasoline use (US Environmental Protection Agency, 2001; Nevin, 2000; US Census, 1975). Early-1940s refinery lead includes aviation fuel used overseas, so blood lead estimates decline with wartime gas rationing (Chevron, 2000).

Fig. 3 shows blood lead estimates for Britain, France, West Germany, Finland, Italy, Canada, Australia, and New Zealand. Estimates are anchored by nation-specific blood lead data because the 55% of gas lead that settled within 20 kilometers of roads caused a higher ratio of blood lead to per capita lead emissions in densely populated nations (Thomas

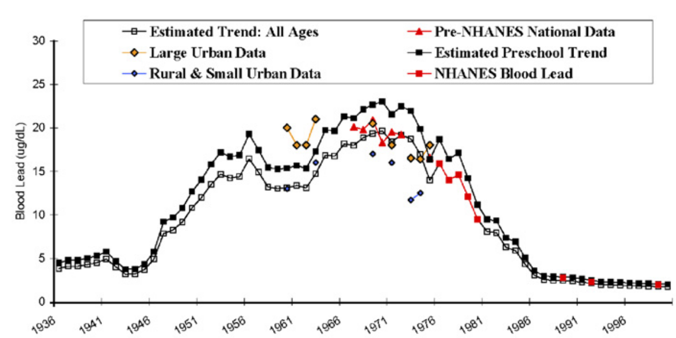

Fig. 2. USA Blood Lead Data and Trend Estimates. Legend: Preschool blood lead estimates reflect 1980–1988 air lead, 1946–1976 refinery lead use (see Fig. 1), and pre-1946 road gasoline use, anchored by NHANES data (which show that 1976–1980 preschool blood lead was higher than blood lead for all ages). Blood lead estimates for all ages are also shown for comparison with other available 1956–1976 survey data on national, large urban area, and small city and rural blood lead levels.

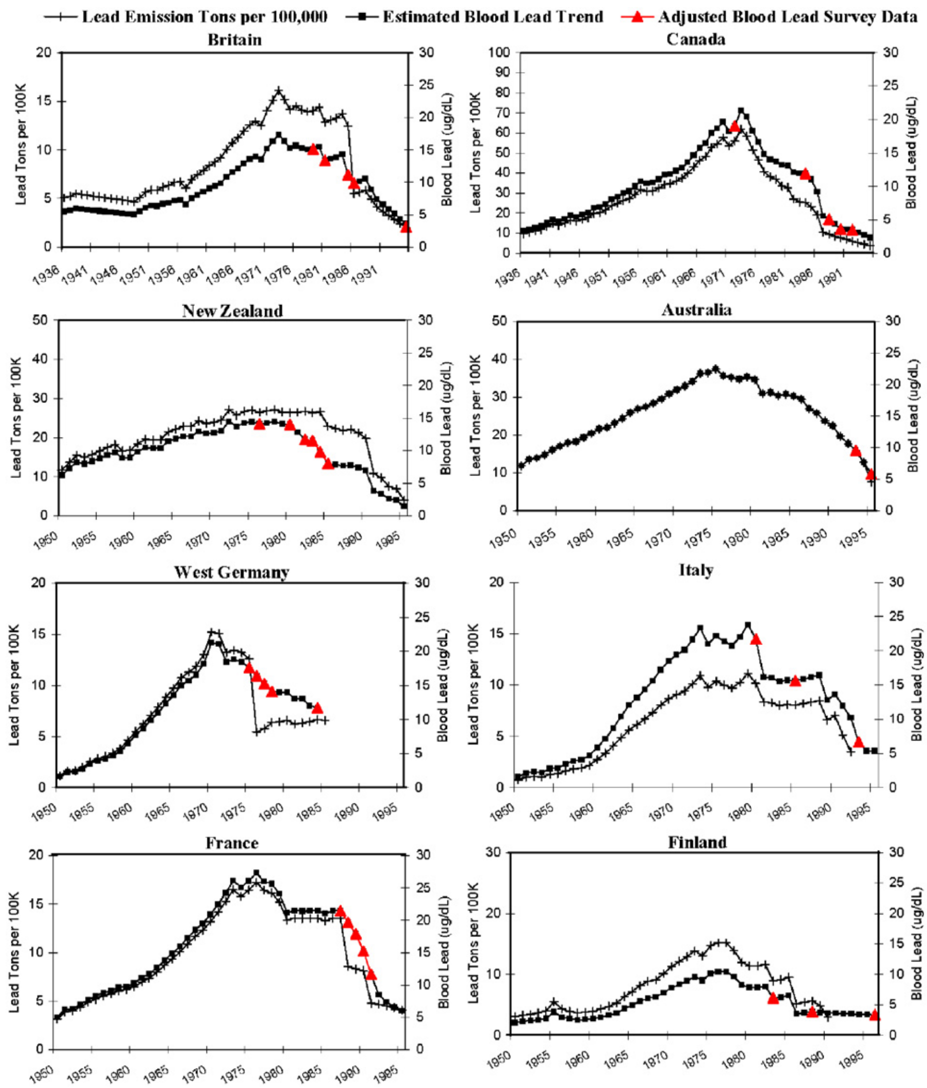

Fig. 3. International Preschool Blood Lead Trend Estimates. Legend: International preschool blood lead estimates reflect lead emission trends, anchored by nation-specific blood lead data because the 55% of gas lead that settled within 20 kilometers of roads caused a higher ratio of blood lead to per capita emissions in densely populated nations.

et al., 1999; Royal Society of Canada, 1986; Organization for Economic Co-Operation and Development, 1993). For some nations, blood lead data for adults, older children, and/or urban populations were adjusted based on NHANES ratios of preschool blood lead to blood lead for other population groups (Pirkle et al., 1994). Gas lead emission trends were available for Canada (Royal Society of Canada, 1986) and British trends reflect post-1969 lead emissions and pre-1970 petrol use (UK Department of Environment, 2004; UK Institute of Petroleum, 1938–1970). Emission trends for other nations reflect leaded gas use and average lead per liter (Organization for Economic Co-Operation and Development, 1993; International Energy Administration, 1960–1990; Octel Ltd, 1969–1990; United Nations, 1950–1960). Data support estimates from 1936 in the USA, Canada, and Britain, and from 1950 in the other six nations. Estimates are subject to blood lead survey random error and some estimation error, but potential error is small relative to the large temporal changes and international divergences in preschool blood lead [Figs. 2 and 3].

Recorded crimes per 100,000 residents are examined for index crime, burglary, robbery, assault, rape, and murder (Barclay and Tavares, 2003; Bureau of Justice Statistics, 2006; Triggs, 1997; UK Home Office, 2004; Statistics Canada, 2005; Mukherjee, et al., 1997; Australian Institute of Criminology, 1999–2006; Council of Europe, 2000, 2003; New Zealand Police, 2001, 2005; Interpol, 2005). Index crime for West Germany, France, and Italy appear to be comparable to USA rates, while Britain, Canada, Australia, Finland, and New Zealand include a broader range of crimes, resulting in higher index rates. USA, Canada, Australia, New Zealand, West Germany, and post-1968 Britain burglary rates are comparable, as are USA, Australia, Britain, Canada, New Zealand, and West Germany robbery rates. Britain only recorded pre-1969 burglaries over a monetary threshold, and low rates in France (not well-documented) may also reflect a threshold. British ''wounding'' is comparable to USA aggravated assault (Langan and Farrington, 1998) and French assault data appear to be comparable. The USA, Britain, France, and Finland report rape of female, and Australia, New Zealand, and Canada report violent and sexual assaults.

Single and combined nation regressions were run with 5–45 year lags to identify ''best-fit'' lags for each crime, with the highest significance (t-value) for blood lead and percent of crime rate variation explained (R^2). Regressions were also run with unemployment rates for nations with comparable data (Bureau of Labor Statistics, 2004). Combined nation results are reported for best-fit lags with and without country dummies. Crime recording, cultural, and other country differences will lower R^2 in the combined nation index crime regression without dummies, and to a lesser extent in other combined nation regressions without dummies. To illustrate "best-fit" lags, Fig. 6 graphs R^2 across single-nation regression time lags for different crime categories, and Figs. 7–11 show crime versus blood lead trend graphs for best-fit lags. Regression results reflect data through 2002, but some graphs include data through 2004. Other potential confounders were excluded because preliminary analysis showed no impact on long-term crime trends. The percent of USA violent crime involving guns was fairly stable from 1973–2004 (Bureau of Justice Statistics, 2005), as violent crime rose and fell sharply. Only 6% of murders in 1991 and 4% in 2001 were linked to drug offenses or brawls influenced by narcotics, and there was little 1990s change in the percent of prisoners who committed crimes to get drug money (Dorsey et al., 2005), as murder and other crimes fell sharply. International crime trends are inconsistent with theoretical effects of police per capita, incarceration, and demographic trends (Barclay and Tavares, 2003; US Census, 2004).

2.3. *Cross-sectional regression analysis of 1985–1994 USA central city murder rates*

A separate analysis compares average 1985–1994 murder rates across USA cities with differences in circa-1970 lead paint poisoning and air lead exposure. Children under seven in 1970 were in the high murder offense age bracket in 1985–1994. "LP%" values were constructed to estimate the percent of each city's 1985–1994 population that had severe childhood lead paint poisoning in 1970. City size dummy variables were used as indicators of 1970 air lead.

Gilsinn (1972) used population under seven and deteriorated and dilapidated housing prevalence to estimate the number of children with blood lead over 40 μg/dL in each 1970 metro area. These estimates approximate the number of central city children over 40 μg/dL because there was little deteriorated housing in 1970 suburbs. Gilsinn's estimates were divided by average 1985–1994 population for the corresponding cities to calculate LP%. Regression analysis compares LP% with the average 1985–1994 murder rates in 124 central city/cities, including 11 combined city murder rates calculated for metro areas with more than one central city. This regression does not reflect air lead variations because Gilsinn's estimates were based on housing data. A second regression compares city murder rates with city size dummy variables as indicators of 1970 air lead, using average 1985–1994 population and murder rates for the same 124 city/cities. A third regression with LP% and city size dummies examines the additive effect of severe lead paint hazards and air lead. The analysis also tests for the effect of the black percent of city population. Limitations of this analysis include cities in the small size category with air lead affected by large cities in another metro area (e.g., Newark and New York), children that moved between cities from 1970 to 1985–94, and 1970 city lead paint poisoning that is overstated to the extent that suburbs did have some deteriorated housing (reflected in Gilsinn's estimates).

3. Results

3.1. *Arrest rate and incarceration trends*

Age-14 British males had the highest caution and conviction rate for indictable offenses in 1958, but peak offending shifted to age 18 by 1997. The age-10 offense rate fell 70% from 1958–1997, as age 18–29 offending rates increased three to five-fold. Males ages 12–14 in 1958, born as gas lead exposure rose after World War II, had higher offending rates than older teens born before that rise in lead exposure. By 1997, offending declined relative to 1958 only for males under 14, born after the mid-1980s fall in British gas lead use, while offending rates rose for older teens and adults born over years of rising gasoline lead use.

USA per capita gasoline lead increased 400% from 1945–55, and Fig. 4 shows the California juvenile index crime arrest rate surged almost 300% from 1965 to 1975. The adult arrest rate rose at a much slower rate, when most adults were born before the 1950s surge in gasoline lead use. Those trends reversed in the 1990s when arrest rates fell faster for juveniles, born after air lead peaked in the early-1970s. In 1975, California's juvenile index crime arrest rate was twice the adult rate, but 2000–2004 index crime arrest rates were higher for adults. (The 1965–1975 arrest rate trends partly reflect inflation increasing the percent of thefts exceeding a monetary threshold, revised over time, but this would not affect juvenile arrest rates relative to adults.)

Property crime accounts for over 90% of index crimes. The overall USA property crime rate was about the same in 1970 and 2003, but the property crime arrest rate for youths under age 15 fell 45% from 1970–2003, the age 15–17 rate fell 27%, the age 18–24 rate rose 8%, and the arrest rate for adults over-24 rose 58%. The 45% drop in the under-15 arrest rate compares offenders in 1970 born near the 1956 interim peak in gasoline lead versus offenders in 2003 born after the early-1980s fall in gasoline lead. The 58% increase in the over-24 arrest rate compares adults in 1970 mostly born before 1950 versus their 2003 counterparts born before 1980.

Fig. 5 compares 1980–2001 age-specific USA arrest rates and 1980–2003 juvenile arrest rates by race. The 1980–2001 USA property crime decline was led by a 70% fall in the black juvenile burglary arrest rate, which fell much faster than the white juvenile arrest rate from 1980–1988, narrowing the racial difference. Juvenile burglary rates were little changed from 1988–1994, but fell further after 1994. The 2003 black juvenile burglary arrest rate was 43% below the 1980 white juvenile rate. Peak offending for

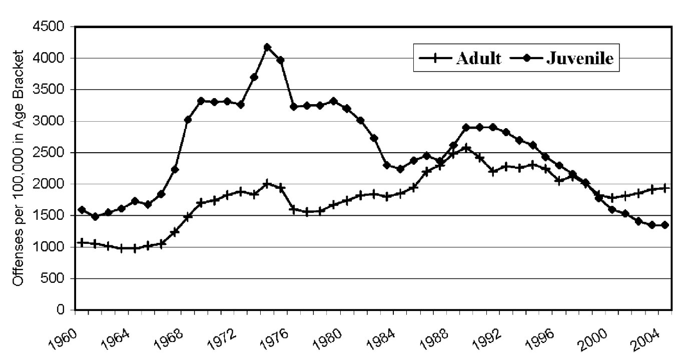

Fig. 4. California Adult and Juvenile Index Crime Arrest Rates. Legend: California Department of Justice (2005) data show the juvenile index crime arrest rate rose much faster than the adult arrest rate from 1965–1975, when most adults were born before the 1950s rise in gasoline lead use. Those trends reversed in the 1990s when arrest rates fell faster for juveniles, born after air lead peaked in the early-1970s. (Arrest trends from 1965–1975 partly reflect inflation increasing the percent of thefts exceeding a monetary threshold, revised over time, but this would not affect juvenile arrest rates relative to adults.)

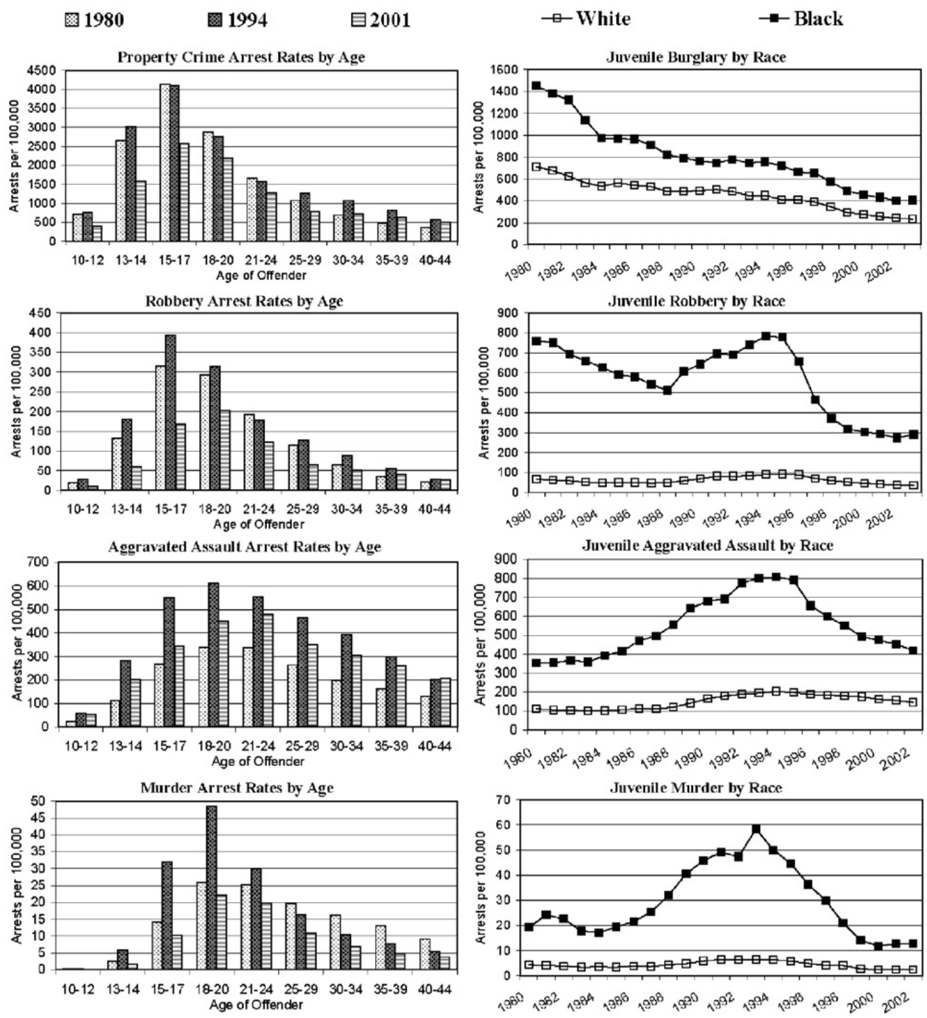

Fig. 5. USA Age-Specific Arrest Rates and Juvenile Arrest Rates by Race. Legend: The USA crime decline was led by a sharp decline in offending by juveniles, and especially black juveniles, as arrest rates changed little for those over age 35. The 1980s racial convergence in juvenile burglary arrest rates could reflect a 1960s racial convergence in preschool blood lead as slum demolition reduced lead paint hazards. Juvenile violence also fell from 1980–1984, but black juvenile violence surged in the late-1980s as black juvenile burglary arrests changed little. This could reflect a wider early-1970s black preschool blood lead distribution with more severe lead exposure especially affecting violence (e.g., among youths raised in public housing near circa-1970 highway traffic).

robbery is a few years older than for propety crime, and the 42% fall in the robbery rate from 1980–2001 was entirely due to sharply lower arrest rates for juveniles and young adults, as the age 35–44 arrest rate rose. The black juvenile robbery arrest rate fell from 1980–1988, narrowing the racial difference, but the black rate and racial difference rose from 1988–1994 before falling to new lows in 2001–2003. Aggravated assault offending peaks at an older age than robbery and falls more slowly with age. Aggravated assault arrests rose for all ages from 1980–1994, but the age 40–44 arrest rate continued to rise through 2001. Black juveniles recorded the largest rise from 1985–1994, and the sharpest fall from 1994–2001. The under-21 homicide arrest rate soared from 1984–1994 as the over-25 rate declined, but the 1990s homicide rate decline was mainly due to a sharp fall in the under-21 rate. The black juvenile murder arrest rate drifted lower in the early-1980s then rose sharply before falling to multi-decade lows. The racial difference in juvenile murder arrest rates peaked in 1994, but the 2003 difference was only about one-fourth the average racial difference from 1980–1998.

USA incarceration trends echo arrest trends, as offenders over age 34 accounted for just 27% of prison commitments in 1993 but accounted for 40% in 2001. The overall USA incarceration rate changed little from 2000–2004, but the age 18–19 male incarceration rate fell 30% and the age 20–34 rate fell 7%, as the male incarceration rate rose 5% for ages 35–39, 21% for ages 40–44, 26% for ages 45–54, and 41% for those over 55. Over 60% of prisoners released in both 1983 and 1994 were rearrested within 3 years, but 35% of those released in 1983 were ages 18–25 versus 21% in 1994. Combining prisoner release trends with recidivist offending rates suggests that prisoners released in the prior 3 years committed just 6% of property crimes and 11% of violent crimes in 1979 versus 28% of property crimes and 35% of violent crimes in 2002.

3.2. *Preschool blood lead and international crime trend regressions*

The best-fit time lag for index crime versus preschool blood lead is 19 years in a regression with country dummies comparing 309 years of data across nine nations. The same best-fit time lag is evident in single-nation regressions with and without an unemployment variable. Table 1 shows regression results with a 19-year lag, Fig. 6 graphs R^2 across lags for each nation, and Figs. 7 and 8 graph preschool blood lead trends versus index crime rates with a 19-year lag. Blood lead is highly significant in combined and single-nation regressions with and without country dummies. Unemployment is significant in most nations but its inclusion in the model has no substantive effect on the blood lead coefficient value or significance (t-value), and little impact on crime rate variation explained (R^2). Adding unemployment raises R^2 from: 80% to 81% for the USA; 87% to 90% for Canada; 72% to 84% for France; and

Table 1
Regressions for preschool blood lead vs. index crime with a 19-year lag

Dependent variable	Independent variables	Coefficient	Standard error	t-Value	p-Value	R^2	N
Index Crime—9 Nations Combined	Intercept	3675.09	311.82	11.79	<.0001	0.165	309
	Preschool Blood Lead	176.26	22.67	7.78	<.0001		
Index Crime—9 Nations Combined	Intercept	2791.49	236.94	11.78	<.0001	0.774	309
With County Dummies (not shown)	Preschool Blood Lead	287.71	14.37	20.03	<.0001		
Australia	Intercept	773.36	910.82	0.85	0.4054	0.628	23
	Preschool Blood Lead	287.58	48.31	5.95	<.0001		
Australia with Unemployment Rate	Intercept	1690.66	857.68	1.97	0.0627		
	Preschool Blood Lead	340.78	46.15	7.39	<.0001	0.732	23
	Unemployment Rate	−243.14	87.22	−2.79	0.0114		
Britain	Intercept	−1665.60	268.99	−6.19	<.0001	0.950	47
	Preschool Blood Lead	740.55	25.22	29.37	<.0001		
Britain with Unemployment Rate	Intercept	−1384.25	243.47	−5.69	<.0001		
	Preschool Blood Lead	675.41	31.42	21.50	<.0001	0.963	44
	Unemployment Rate	75.92	41.59	1.83	0.0752		
Finland	Intercept	2312.83	251.41	9.20	<.0001	0.880	33
	Preschool Blood Lead	589.44	39.18	15.05	<.0001		
New Zealand	Intercept	−2123.73	580.89	−3.66	0.0009	0.936	33
	Preschool Blood Lead	1053.89	49.42	21.32	<.0001		
Canada	Intercept	1624.66	363.20	4.47	<.0001	0.868	41
	Preschool Blood Lead	440.00	27.52	15.99	<.0001		
Canada with Unemployment Rate	Intercept	863.50	397.25	2.17	0.036		
	Preschool Blood Lead	336.40	39.75	8.46	<.0001	0.897	41
	Unemployment Rate	280.76	84.73	3.31	0.002		
USA	Intercept	1629.13	241.54	6.74	<.0001	0.798	43
	Preschool Blood Lead	193.30	15.21	12.71	<.0001		
USA with Unemployment Rate	Intercept	1215.54	364.51	3.33	0.0018		
	Preschool Blood Lead	181.81	16.84	10.80	<.0001	0.808	43
	Unemployment Rate	98.61	65.83	1.50	0.142		
W. Germany	Intercept	4012.72	209.23	19.18	<.0001	0.834	22
	Preschool Blood Lead	185.25	18.49	10.02	<.0001		
W. Germany with Unemployment Rate	Intercept	3750.86	156.98	23.89	<.0001	0.923	22
	Preschool Blood Lead	87.91	24.57	3.58	0.002		
	Unemployment Rate	307.25	65.89	4.66	0.0002		
Italy	Intercept	830.33	111.88	7.42	<.0001	0.928	33
	Preschool Blood Lead	148.97	7.46	19.96	<.0001		
Italy with Unemployment Rate	Intercept	737.51	153.03	4.82	<.0001	0.930	33
	Preschool Blood Lead	135.58	16.77	8.09	<.0001		
	Unemployment Rate	38.56	43.21	0.89	0.3792		
France	Intercept	2386.69	343.82	6.94	<.0001	0.722	34
	Preschool Blood Lead	175.73	19.27	9.12	<.0001		
France with Unemployment Rate	Intercept	1889.03	289.49	6.53	<.0001		
	Preschool Blood Lead	28.18	35.29	0.80	0.4306	0.836	34
	Unemployment Rate	367.66	79.51	4.62	<.0001		

Legend: Regressions combining data for nine nations were run for preschool blood lead versus index crime with time lags of 5–45 years, and the best-fit lag (highest R^2 & t-value for blood lead) was 19 years. Recording differences lower R^2 in the combined regression without country dummies but blood lead is still highly significant. Blood lead is also significant and R^2 is high in each single-nation regression with a 19-year lag. Unemployment is significant but has little incremental effect on regression R^2.

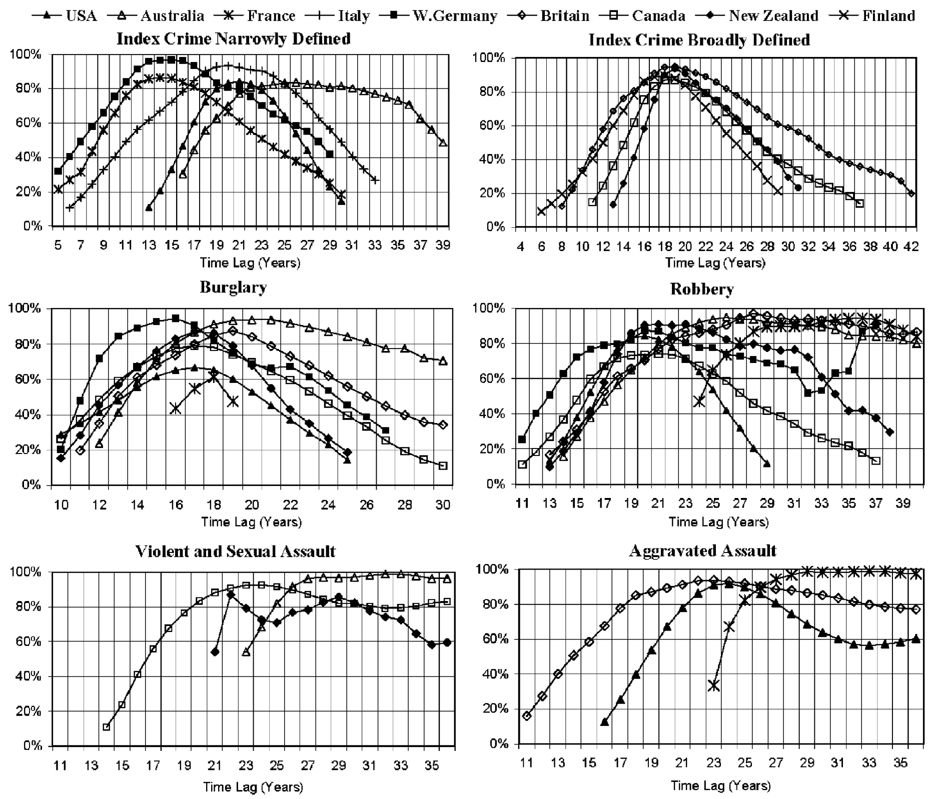

Fig. 6. R^2 across Single-Nation Regression Time Lags. Legend: Single-nation regressions were run with 5–45 year lags for each crime category versus preschool blood lead, for every nation with available data. Despite divergent international crime and blood lead trends, regression R^2 (and blood lead t-value) is near its peak in each nation at time lags consistent with peak offending ages for each crime category.

83% to 92% for West Germany. Italy and Britain R^2 with just blood lead is 93% to 95% and unemployment is insignificant. Graphs across time lags show R^2 (and blood lead t-value) peaks at 18–21 years in six nations, at 14–15 years in West Germany ($N = 22$) and France ($N = 33$) and 26 years in Australia ($N = 23$).

The best-fit lag for burglary is 18 years in a combined regression for eight nations ($N = 229$) with country dummies, and for five nations ($N = 169$) with unemployment data (excluding burglary data for France suggesting a monetary threshold). Table 2 shows blood lead is highly significant in combined and single-nation burglary regressions. Fig. 6 shows R^2 across time lags for each nation, and Fig. 9 graphs burglary versus blood lead with an 18-year lag. Unemployment is significant but its inclusion only increases R^2 from 65% to 73% for the USA; 78% to 86% for Canada; 85% to 88% for Britain; and 82% to 92% for West Germany. Australia R^2 is 91% with just blood lead (unemployment is insignificant) and New Zealand R^2 is 86% with just blood lead. R^2 peaks at lags of 16–19 years in seven nations, and 21 years in Australia, based on data through 2002. Australia's burglary rate fell about 20% from 2002–2004.

The best-fit lag for robbery across seven nations ($N = 220$) is 23 years, and unemployment is insignificant across six nations ($N = 190$). Table 3 shows blood lead with a 23-year lag is highly significant in combined and single-nation regressions. Fig. 10 graphs robbery versus blood lead with a 23-year lag. Adding unemployment raises R^2 somewhat for the USA and Canada but unemployment is insignificant or has an unexpected sign in other nations. The best fit is 20–21 years in four nations, 36 years in France ($N = 14$) and 26–28 in Britain and Australia through 2002. Britain and Australia robbery rates fell about 20% from 2002–2004.

Table 4 and Fig. 11 show blood lead with a 23-year lag is highly significant in regressions for aggravated assault ($N = 100$) and violent and sexual assault ($N = 67$), and with a 24-year lag for rape ($N = 113$). Unemployment is insignificant. The best-fit for aggravated assault is 24 years in the USA ($N = 43$), 23 in Britain ($N = 43$), and 29–33 years in France ($N = 14$). The best fit lag for violent and sexual assault is 24 years in Canada ($N = 41$), 22 in New Zealand ($N = 15$), and 28–33 in Australia ($N = 11$). The best-fit for rape is 23 years in the USA ($N = 43$), 30 in Britain ($N = 43$), 29 in France ($N = 14$), and 27–33 in Finland ($N = 13$). Fig. 6 shows regression R^2 for aggravated assault, violent and sexual assault, and rape reach absolute peaks across a range of longer lags in single-nation regressions. However, Table 4 shows R^2 and t-values are very high with the 23–24 year time lag for all single-nation regressions with over 14 years of data (R^2 of 79–94%). Table 5 shows blood lead with an 18-year

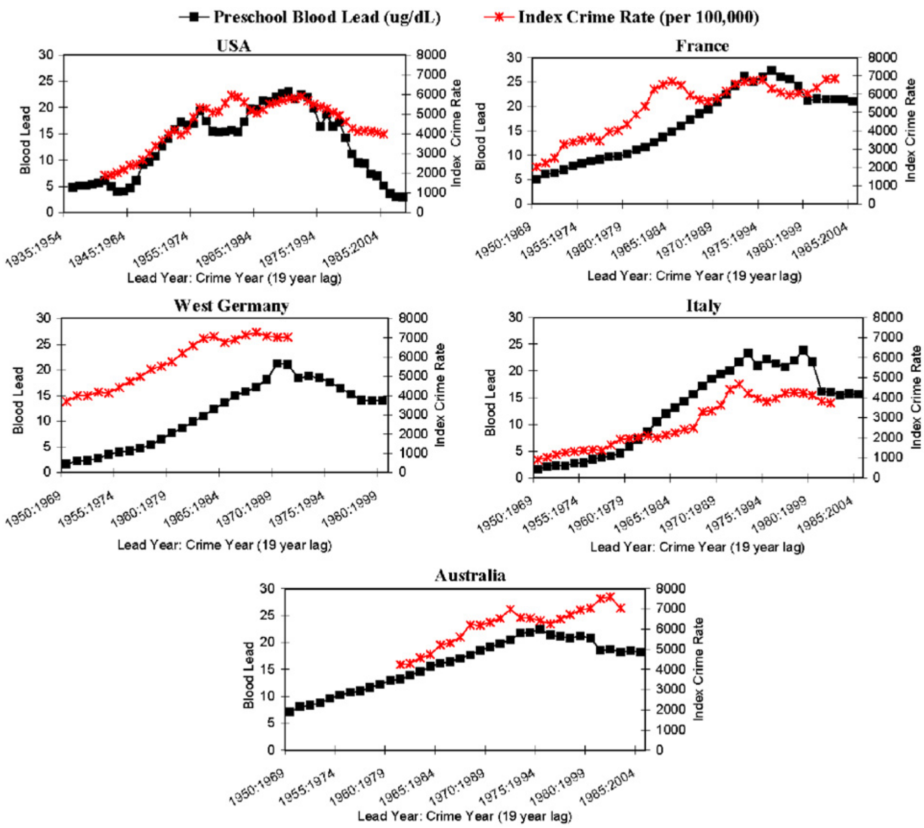

Fig. 7. Preschool Blood Lead vs. Narrowly Defined Index Crime with a 19-Year Lag. Legend: USA index crime includes property crimes (theft and burglary) and the violent crimes of murder, rape, robbery, and aggravated assault (causing injury or with a lethal weapon). Nations with comparable crime indexes all show index crime rates tracking preschool blood lead trends with a 19 year lag, despite divergent crime trends. The USA index crime rate was 22% higher than the French rate and 40% higher than Australia's rate in 1980, but the USA rate was 39% below the French rate and 45% below Australia's rate in 2001.

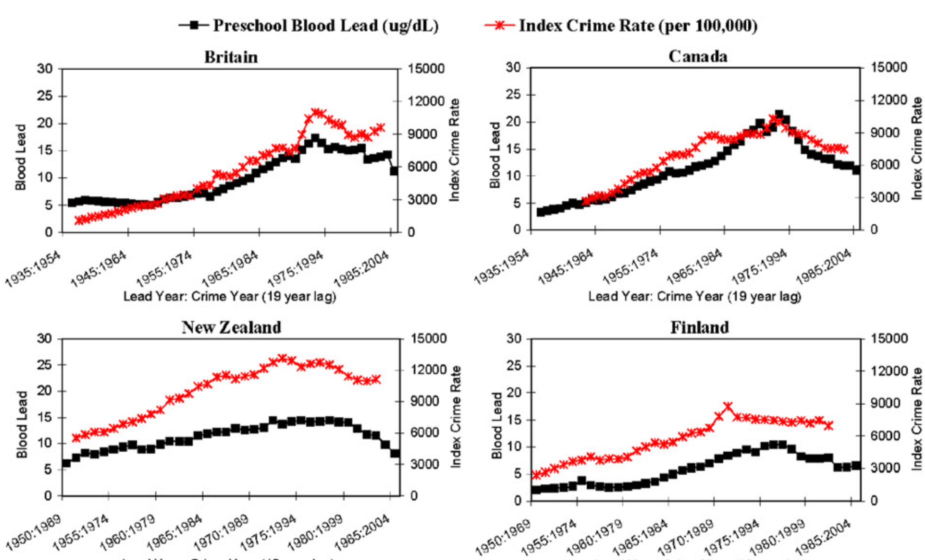

Fig. 8. Preschool Blood Lead vs. Broadly Defined Index Crime with a 19-Year Lag. Legend: Broadly defined index crime rates include USA index crimes plus threats, assaults without injury, and thefts below a USA monetary threshold. Despite recording differences and divergent crime trends, broadly defined index crime rates also track blood lead trends with a 19-year lag.

lag is significant in the combined nation murder regression ($N = 209$) and unemployment is insignificant ($N = 178$). The best-fit time lag is 18–19 years for the USA, New Zealand, and Britain, but Canada has a shorter best-fit and average preschool blood lead is not significant in murder regressions for Australia or West Germany.

Table 2
Regressions for preschool blood lead vs. burglary with an 18-year lag

Dependent variable	Independent variable	Coefficient	Standard error	t-Value	p-Value	R^2	N
Burglary—8 Nations Combined	Intercept	1072.11	106.53	10.06	<.0001	0.060	229
(UK, US, CAN, AUS, NZ, WG, FR, FIN)	Preschool Blood Lead	27.63	7.23	3.82	0.0002		
Burglary—8 Nations Combined	Intercept	626.50	73.09	8.57	<.0001	0.776	229
With County Dummies (not shown)	Preschool Blood Lead	83.33	4.56	18.26	<.0001		
Burglary—5 Nations Combined	Intercept	586.49	107.04	5.48	<.0001	0.299	169
(UK, US, CAN, AUS, WG)	Preschool Blood Lead	61.76	7.32	8.44	<.0001		
Burglary—5 Nations Combined	Intercept	714.88	64.32	11.11	<.0001	0.819	169
With County Dummies (not shown)	Preschool Blood Lead	75.81	4.08	18.59	<.0001		
Burglary—5 Nations Combined	Intercept	397.60	67.85	5.86	<.0001	0.869	169
With County Dummies (not shown) and Unemployment Rate	Preschool Blood Lead	53.91	4.44	12.15	<.0001		
	Unemployment Rate	78.91	9.96	7.92	<.0001		
USA Burglary	Intercept	397.67	84.11	4.73	<.0001	0.653	43
	Preschool Blood Lead	46.52	5.29	8.79	<.0001		
USA Burglary with Unemployment Rate	Intercept	112.06	115.39	0.97	0.3373		
	Preschool Blood Lead	38.85	5.30	7.32	<.0001	0.727	43
	Unemployment Rate	67.47	20.59	3.28	0.0022		
Britain Burglary	Intercept	−51.84	129.15	−0.40	0.6908	0.849	34
	Preschool Blood Lead	141.04	10.52	13.41	<.0001		
Britain Burglary with Unemployment Rate	Intercept	−147.83	119.74	−1.23	0.2263	0.883	34
	Preschool Blood Lead	121.74	11.38	10.70	<.0001		
	Unemployment Rate	44.33	14.72	3.01	0.0051		
Canada Burglary	Intercept	245.40	75.37	3.26	0.0023	0.781	41
	Preschool Blood Lead	66.79	5.66	11.79	<.0001		
Canada Burglary with Unemployment Rate	Intercept	69.76	72.04	0.97	0.339	0.860	41
	Preschool Blood Lead	38.85	7.61	5.11	<.0001		
	Unemployment Rate	72.30	15.68	4.61	<.0001		
Australia Burglary	Intercept	−544.87	133.16	−4.09	0.0003	0.912	31
	Preschool Blood Lead	132.38	7.65	17.31	<.0001		
Australia Burglary with Unemployment Rate	Intercept	−538.67	133.18	−4.04	0.0004		
	Preschool Blood Lead	121.97	12.70	9.60	<.0001	0.915	31
	Unemployment Rate	24.43	23.82	1.03	0.314		
W. Germany Burglary	Intercept	1403.17	95.86	14.64	<.0001	0.819	20
	Preschool Blood Lead	65.42	7.26	9.01	<.0001		
W. Germany Burglary with Unemployment Rate	Intercept	1274.62	69.79	18.26	<.0001	0.923	20
	Preschool Blood Lead	31.58	8.59	3.67	0.0019		
	Unemployment Rate	120.45	25.18	4.78	0.0002		
France Burglary	Intercept	261.69	105.51	2.48	0.0289	0.614	14
	Preschool Blood Lead	19.31	4.42	4.36	0.0009		
France Burglary with Unemployment Rate	Intercept	272.37	114.21	2.38	0.0362		
	Preschool Blood Lead	20.30	5.47	3.71	0.0034	0.617	14
	Unemployment Rate	−3.33	9.96	−0.33	0.7447		
Finland Burglary	Intercept	1065.13	378.40	2.81	0.0202	0.286	11
	Preschool Blood Lead	78.62	41.43	1.90	0.0902		
New Zealand Burglary	Intercept	−1153.40	205.29	−5.62	<.0001	0.862	35
	Preschool Blood Lead	254.37	17.73	14.35	<.0001		

Legend: Combined-nation regressions for preschool blood lead versus burglary with time lags of 5–45 years showed a best-fit lag of 18 years. Blood lead is also significant and R^2 is high with an 18-year lag in all single-nation regressions with $N>11$. Unemployment is statistically significant but has little incremental effect on regression R^2.

3.3. *Cross-sectional regression analysis of 1985–1994 USA central city murder rates*

Table 6 shows the regression analyses of 1985–1994 average murder rates across 124 central city/cities. The average 1985–1994 murder rate was 33 (per 100,000) in central city/cities with population over a million, 21 in cities of 250,000 to one million, and 15 in cities of 100–250 thousand, and city size dummy variables are significant in a simple regression, with R^2 of 11.4%. LP% is also highly significant in a separate regression, with R^2 of 14%. When LP% and city size are both included, regression R^2 (33%) exceeds the variation explained by separate regressions (11.4% + 13.9% = 25.3%) and LP% and city size variables are more significant (higher t-values). When a variable is added for black percent of population, city size is still significant and LP% is not (t-value = 1.27), but the LP% coefficient still has the expected sign and retaining LP% in the model increases R^2 to 69% versus 61% with just the city size and black percent variables.

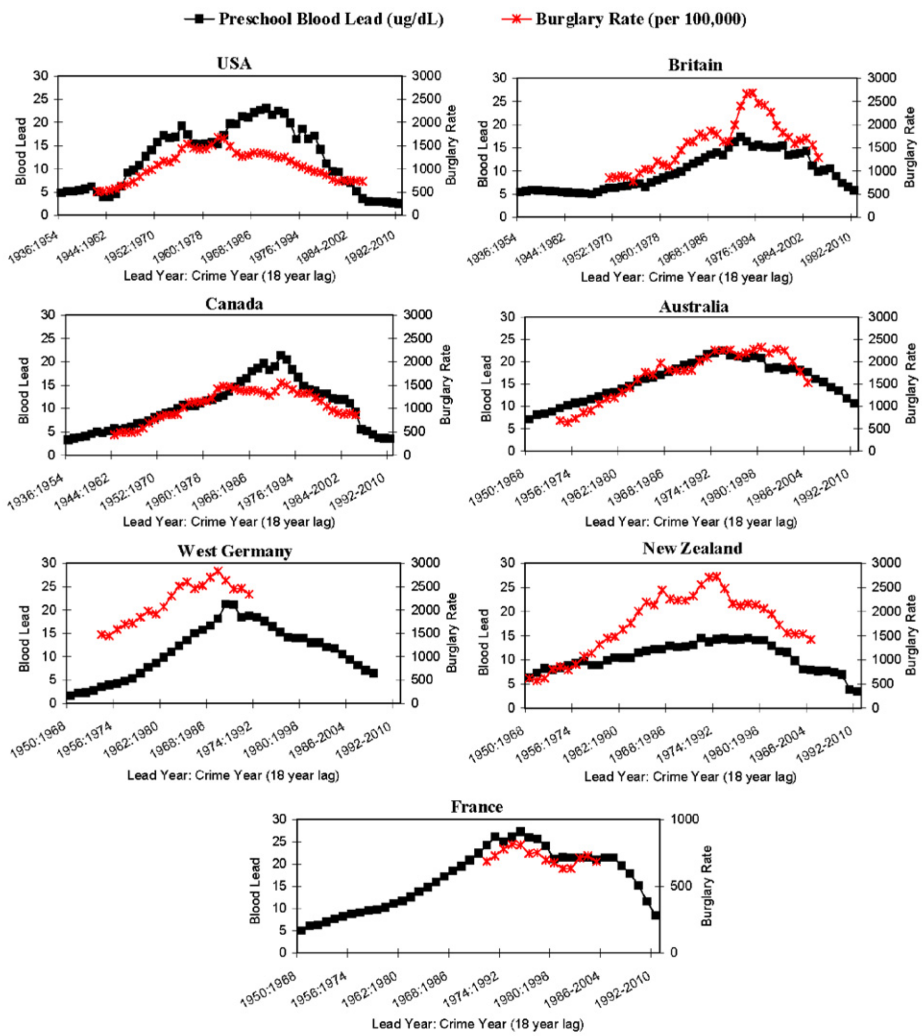

Fig. 9. Preschool Blood Lead vs. Burglary with an 18-Year Lag. Legend: The best-fit lag for preschool blood lead versus burglary is 18 years in a combined-nation regression. The 1974 USA burglary rate was 50% and 98% higher than rates in Britain and Australia, respectively, and the 2002 USA rate was 56% and 63% lower than rates in Britain and Australia, but preschool blood lead trends presaged burglary rate trends with an 18-year lag in each nation.

4. Discussion

4.1. Arrest rate and incarceration trends

The 1980s racial convergence in juvenile burglary rates could reflect a 1960s racial convergence in preschool blood lead due to slum demolition and a 1956–1962 fall in per capita gas lead use, even as urban sprawl spread more gas lead emissions to predominantly white suburbs. A 1960s blood lead convergence is also consistent with a racial convergence in National Assessment of Educational Progress (NAEP) scores reported for the same birth cohort (Neisser et al., 1996). A 2003 black juvenile burglary arrest rate that was well below the 1980 white juvenile arrest rate is also consistent with late-1980s average black preschool blood lead well below the 1970s average for white children (Pirkle et al., 1994).

Juvenile violence also fell from 1980–1984, but black juvenile violence surged in the late-1980s as black NAEP scores and juvenile burglary arrests changed little. These trends could reflect a wider early-1970s black preschool blood lead distribution with more severe exposure especially affecting violence. Average black lead exposure might have changed little from the mid-1960s to the early-1970s as declining lead paint hazards offset the rise in ambient air lead, but severe poisoning prevalence likely rose among black children living near urban highways. A stronger association between severe lead poisoning and violence is also consistent with racial differences in late-1970s blood lead and early-1990s juvenile arrest rates. Average 1976–1980 blood lead for black children ages 6–36 months was 50% above the average for white children, but blacks were six times more likely to have blood lead of 30–39 μg/dL and eight times more likely to be over 40 μg/dL. Those children were juveniles when the 1990–1994 black juvenile burglary arrest rate was 60% higher than the white rate, but the black juvenile violent crime arrest rate was five times higher and the black juvenile murder rate was eight times higher.

Table 3
Regressions for preschool blood lead vs. robbery with a 23-year lag

Dependent variable	Independent variable	Coefficient	Standard error	*t*-Value	*p*-Value	R^2	*N*
Robbery—7 Nations Combined	Intercept	−11.96	8.06	−1.48	0.1391		
(UK, US, CAN, AUS, NZ, WG, FR)	Preschool Blood Lead	7.88	0.58	13.64	<.0001	0.461	220
Robbery—7 Nations Combined	Intercept	−9.41	5.59	−1.68	0.0937	0.848	220
With County Dummies (not shown)	Preschool Blood Lead	7.42	0.39	18.89	<.0001		
Robbery—6 Nations Combined	Intercept	−1.56	8.42	−0.19	0.853	0.472	190
(UK, US, CAN, AUS, WG, FR)	Preschool Blood Lead	7.64	0.59	12.97	<.0001		
Robbery—6 Nations Combined	Intercept	−9.94	6.05	−1.64	0.1021	0.830	190
With County Dummies (not shown)	Preschool Blood Lead	7.47	0.43	17.41	<.0001		
Robbery—6 Nations Combined	Intercept	−9.54	7.77	−1.23	0.2211	0.830	190
With County Dummies (not shown) and Unemployment Rate	Preschool Blood Lead	7.49	0.50	15.10	<.0001		
	Unemployment Rate	−0.09	1.14	−0.08	0.9349		
USA Robbery	Intercept	56.45	13.23	4.27	0.0001	0.715	43
	Preschool Blood Lead	8.55	0.84	10.14	<.0001		
USA Robbery with Unemployment Rate	Intercept	6.99	20.43	0.34	0.7341		
	Preschool Blood Lead	7.63	0.83	9.20	<.0001	0.767	43
	Unemployment Rate	10.59	3.53	3.00	0.0046		
Britain Robbery	Intercept	−65.95	9.30	−7.09	<.0001	0.843	43
	Preschool Blood Lead	13.40	0.90	14.83	<.0001		
Britain Robbery with Unemployment Rate	Intercept	−59.04	9.70	−6.08	<.0001		
	Preschool Blood Lead	14.37	1.01	14.20	<.0001	0.856	43
	Unemployment Rate	−2.55	1.33	−1.91	0.0627		
Canada Robbery	Intercept	26.20	5.81	4.51	<.0001	0.712	41
	Preschool Blood Lead	4.50	0.46	9.82	<.0001		
Canada Robbery with Unemployment Rate	Intercept	3.66	6.73	0.54	0.5899	0.817	41
	Preschool Blood Lead	2.84	0.51	5.55	<.0001		
	Unemployment Rate	5.74	1.23	4.68	<.0001		
Australia Robbery	Intercept	−56.19	8.05	−6.98	<.0001	0.890	30
	Preschool Blood Lead	7.47	0.50	15.03	<.0001		
Australia Robbery with Unemployment Rate	Intercept	−41.11	8.20	−5.01	<.0001		
	Preschool Blood Lead	8.49	0.52	16.27	<.0001	0.922	30
	Unemployment Rate	−4.34	1.29	−3.37	0.0023		
W. Germany Robbery	Intercept	30.36	1.77	17.19	<.0001	0.802	19
	Preschool Blood Lead	1.60	0.19	8.29	<.0001		
W. Germany Robbery with Unemployment Rate	Intercept	27.80	2.38	11.69	<.0001	0.828	19
	Preschool Blood Lead	1.33	0.26	5.21	<.0001		
	Unemployment Rate	1.02	0.66	1.54	0.1421		
France Robbery	Intercept	23.62	82.89	0.28	0.7806	0.176	14
	Preschool Blood Lead	5.69	3.55	1.60	0.1351		
France Robbery with Unemployment Rate	Intercept	225.89	69.68	3.24	0.0078		
	Preschool Blood Lead	8.40	2.32	3.62	0.004	0.700	14
	Unemployment Rate	−25.77	5.88	−4.39	0.0011		
New Zealand Robbery	Intercept	−36.36	4.12	−8.83	<.0001	0.908	30
	Preschool Blood Lead	5.97	0.36	16.66	<.0001		

Legend: The best-fit lag for preschool blood lead versus robbery is 23 years in regressions combining data for seven nations. Unemployment is insignificant. Blood lead is highly significant and R^2 is high with a 23-year lag in all single-nation regressions with $N > 14$.

Moffitt (1993) distinguishes between relatively common Adolescence-Limited (AL) offenders and more violent Life-Course-Persistent (LCP) offenders who account for most adult offending. Shifts in juvenile index crime and property crime arrest rates suggest that preschool blood lead has a major impact on AL offending. However, the 2003 USA age 15–17 property crime arrest rate was still seven times the rate for adults over age 24, showing AL offending is more common across birth cohorts with very different preschool blood lead. Rising arrest and incarceration rates for older adults suggest that LCP offending could also be related to preschool blood lead. Brain growth also presents intriguing parallels with lifetime offending in one sample of juvenile criminals: Offense rates rose sharply after age 10; property crimes peaked in adolescence and fell almost 90% by the early-20s; and violent offending peaked in the early-20s and fell after age 30 with a sharp decline by age 50 even among high-rate chronic violent offenders (Sampson and Laub, 2003). These patterns parallel brain development from the surge in offending and gray matter growth near puberty, through gray matter and offending peaks around age 20, to the peak in white matter and a sharp reduction in offending by age 50.

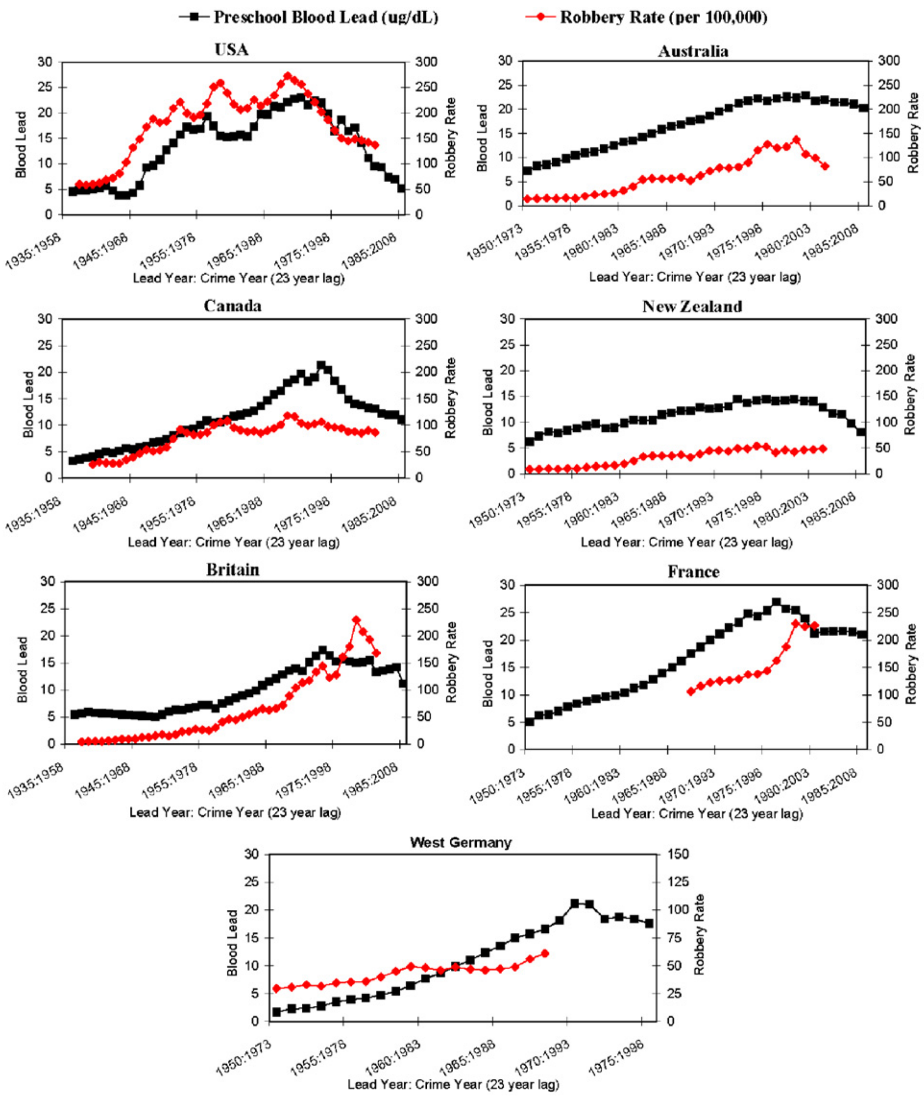

Fig. 10. Preschool Blood Lead vs. Robbery with a 23-Year Lag. Legend: The best-fit lag for preschool blood lead versus robbery is 23 years in a combined-nation regression. The Canadian robbery rate was five times the rate in Britain in 1962, but the 2002 Canadian rate was less than half the rate in Britain.

4.2. *Preschool blood lead and international crime trends*

It is striking that preschool blood lead is highly significant at best-fit lags consistent with peak offending ages for each crime category. Burglary and other property crime arrests peak at ages 15–20, and the best-fit for burglary is 18 years in combined nation regressions and 16–19 years in separate regressions for the USA, Canada, Britain, France, Finland, West Germany, and New Zealand. Aggravated assault peaks from age 18 to the late-20s, and the best-fit is 22–24 years for aggravated assault in the USA and Britain and for violent and sexual assault in Canada and New Zealand. Robbery arrests peak from age 15 to the mid-20s, and the best-fit lag is 23 years in a combined regression and 20–21 years for the USA, Canada, West Germany, and New Zealand. The best-fit lag for index crime is 18–21 years in the USA, Britain, Canada, Italy, Finland, and New Zealand. Some nations show longer best-fits for some crimes, but blood lead is generally still highly significant at the international best-fit for that category.

Although time series comparisons can result in coincidental correlations, no nation shows any correlation between burglary and blood lead at lags of less than 10 or over 38 years—the blood lead coefficient in such regressions is insignificant. No nation shows any significant relationship between robbery or violent and sexual assault versus blood lead with a lag of less than 11 years, between aggravated assault and blood lead with a lag of less than 14 years, or between rape and blood lead with a lag of less than 13 years. Changes in R^2 when unemployment is added are also consistent with other evidence that unemployment has a substantively small effect on property crime (burglary and most index crime) and no clear relationship with violence.

Table 4
Regressions for preschool blood lead vs. aggravated assault and violent & sexual assault with a 23-year lag, and vs. rape with a 24-year lag

Dependent variable	Independent variable	Coefficient	Standard error	t-Value	p-Value	R^2	N
Ag Assault—3 Nations Combined	Intercept	99.05	25.79	3.84	0.0002		
(UK, US, FR)	Preschool Blood Lead	9.99	1.71	5.84	<.0001	0.258	100
Ag Assault—3 Nations Combined	Intercept	18.92	14.57	1.30	0.1974		
With County Dummies (not shown)	Preschool Blood Lead	22.25	1.20	18.54	<.0001	0.803	100
USA Ag Assault	Intercept	20.63	13.20	1.56	0.1257		
	Preschool Blood Lead	17.19	0.84	20.44	<.0001	0.911	43
Britain Ag Assault	Intercept	−116.81	15.14	−7.71	<.0001		
	Preschool Blood Lead	36.62	1.47	24.89	<.0001	0.938	43
France Ag Assault	Intercept	−43.43	76.27	−0.57	0.5796		
	Preschool Blood Lead	8.01	3.27	2.45	0.0304	0.334	14
V&S Assault—3 Nations Combined	Intercept	257.07	57.84	4.44	<.0001		
(CAN, AUS, NZ)	Preschool Blood Lead	32.28	3.99	8.08	<.0001	0.501	67
V&S Assault—3 Nations Combined	Intercept	73.31	37.24	1.97	0.0534		
With County Dummies (not shown)	Preschool Blood Lead	46.66	2.93	15.92	<.0001	0.844	67
Canada V&S Assault	Intercept	96.19	26.13	3.68	0.0007		
	Preschool Blood Lead	44.69	2.06	21.69	<.0001	0.923	41
New Zealand V&S Assault	Intercept	−1510.00	341.19	−4.43	0.0007		
	Preschool Blood Lead	178.84	25.40	7.04	<.0001	0.792	15
Australia V&S Assault	Intercept	−842.56	480.61	−1.75	0.1135		
	Preschool Blood Lead	75.25	23.10	3.26	0.0099	0.541	11
Rape—4 Nations Combined	Intercept	−0.14	2.04	−0.07	0.9461		
(UK, USA, FR, FIN)	Preschool Blood Lead	1.23	0.14	8.63	<.0001	0.402	113
Rape—4 Nations Combined	Intercept	−7.51	0.68	−10.99	<.0001		
With County Dummies (not shown)	Preschool Blood Lead	1.39	0.06	24.72	<.0001	0.951	113
USA Rape	Intercept	6.30	1.28	4.94	<.0001		
	Preschool Blood Lead	1.57	0.08	19.11	<.0001	0.899	43
Britain Rape	Intercept	−5.49	0.82	−6.73	<.0001		
	Preschool Blood Lead	1.17	0.08	14.49	<.0001	0.837	43
France Rape	Intercept	−3.35	2.86	−1.17	0.2648		
	Preschool Blood Lead	0.71	0.12	5.71	<.0001	0.731	14
Finland Rape	Intercept	3.39	1.83	1.85	0.0915		
	Preschool Blood Lead	0.62	0.21	2.88	0.015	0.429	13

Legend: In combined nation regressions, the best-fit lag for aggravated assault and for violent and sexual assault is 23 years, and the best fit for rape is 24 years. Blood lead is also significant with a 23/24-year lag in all single-nation regressions. Unemployment is not significant in assault and rape regressions.

The very high significance of blood lead at lags consistent with peak offending ages is especially striking in light of divergent crime rate trends. Canada's index crime rate was 60% higher than the rate in Britain in the early-1970s, but 20% lower in 2001. The USA index rate was 22% higher than the French rate and 40% higher than Australia's rate in 1980, but the USA rate was 39% below the French rate and 45% below Australia's rate in 2001. The 1974 USA burglary rate was 50% and 98% higher than rates in Britain and Australia, respectively, but the 2002 USA rate was 56% and 63% lower than rates in Britain and Australia. The Canadian robbery rate was five times the rate in Britain in 1962, but the 2002 Canadian rate was less than half the rate in Britain. The 1960 USA aggravated assault rate was almost three times the rate in Britain, but the 2002 USA rate was half the rate in Britain. The 1960 USA rape rate was eight times the British rate, but the 2002 USA rape rate was just 50% higher than the British rate.

Index crime recording differences result in lower R^2 (16.5%) in the combined-nation index crime regression without country dummies, but these differences also make the significance of blood lead in this regression more remarkable. The high R^2 (63–93%) in each single-nation index crime regression with a 19-year lag also suggests that blood lead affects many types of criminal behavior including simple assaults and petty thefts. More uniform recording of burglary and robbery result in R^2 of almost 30% in the 5-nation burglary regression without country dummies, and R^2 of 46% in the 7-nation robbery regression without country dummies.

4.3. Cross-sectional analysis of 1985–1994 USA central city murder rates

It is well known that 1980–1994 USA murder rates mainly reflected trends in large cities, but air lead and gasoline lead trends can explain why the largest USA cities had such high murder rates. Cities with population over a million had 1960s air lead about twice the level in cities of 250,000 to a million, which had air lead 40% higher than cities of 100–250 thousand. Average 1985–1994 murder rates in city/cities over a million were then 57% higher than in city/cities of 250,000 to a million, which had average

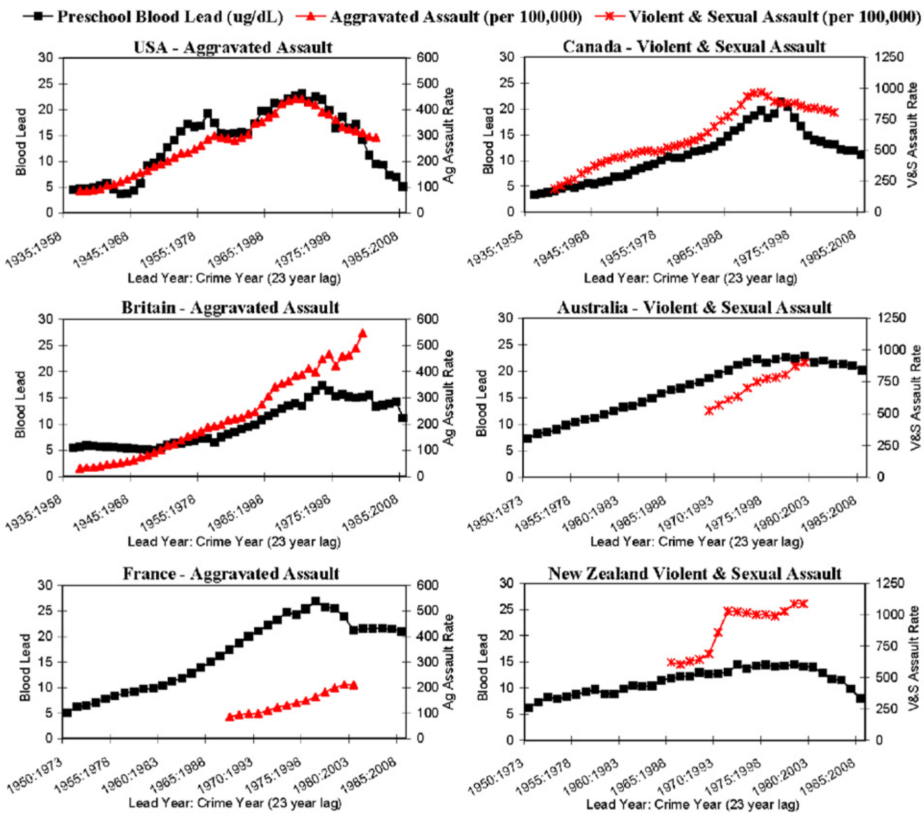

Fig. 11. Preschool Blood Lead vs. Assault with a 23-Year Lag (Aggravated Assault or Violent & Sexual Assault). Legend: In combined nation regressions, the best-fit lag versus blood lead is 23 years for aggravated assault and for violent and sexual assault. The 1960 USA aggravated assault rate was almost three times the British rate, and the 2002 USA rate was half the rate in Britain, yet the best-fit lag is 22–24 years for aggravated assault in single-nation regressions for both the USA and Britain.

1985–1994 murder rates 40% higher than cities of 100–250 thousand. LP%, reflecting 1970 lead paint poisoning, is also highly significant in a simple regression. The regression for city size and LP% yields higher statistical significance (*t*-values) and explanatory power (R^2) than separate simple regressions, consistent with effects of gasoline lead (city size) and lead paint hazards (LP%), plus the additive effect of paint and gasoline lead (not captured by separate regressions for city size and LP%).

An association between murder and more severe lead exposure could explain why West German and Australian blood lead trends show no statistical relationship with recent murder trends. West Germany likely had a low prevalence of severely elevated blood lead due to destruction of old housing (with lead paint) during World War II. Australia data also show a relatively low 1990s prevalence of elevated blood lead even when average preschool blood lead was relatively high. Australian murder rates (and incarceration) did fall from 1900 through the 1940s followed by a long slow rise since the 1940s (Graycar, 2001), consistent with a decline in paint lead exposure followed by rising gasoline lead exposure.

USA lead paint poisoning must have declined as severely deteriorated slums were demolished from the mid-1950s through the 1960s, but the USA murder rate fluctuated from 8 to 10 per 100,000 from 1971–1994. Therefore, the hypothesis that murder is especially associated with severe exposure implies that severe gasoline exposure increased as severe paint hazards declined. Rural and city size murder trends are consistent with that shift. The rural share of the population was 26% in 1980 and in 1990 but the rural share of USA murders fell from 14% in 1976 to 7% in 1994, and total rural murders fell 44% from 1980–1994. That murder decline is consistent with a fall in rural paint lead exposure from 1940–1970, when the average farm home was about 35 years old (US Census, 1975), so half of 1940 farm homes were built before 1905 with highly leaded interior paint, whereas half of 1970 farm homes were built after 1935 when interior lead paint was far less common. Urban air lead rose as lead paint exposure fell, and a 1980s murder decline outside of cities over 100,000 was offset by a sharp rise in large cities with the worst 1960s air lead. From 1981–1991, USA murder rates rose 3% in cities of 100–500 thousand, 9% in cities of 500,000 to 1 million, and 26% in cities over a million. The 1980s phase-out of gas lead left little air lead difference by city size, and average 2000–2002 murder rates were 14.7 (per 100,000) in cities over a million, 14.6 in cities of 500,000 to a million, 15.0 in cities of 250–500 thousand, and 9.5 in cities of 100–250 thousand (Fox and Zawitz, 2004).

Table 5
Regressions for murder vs. preschool blood lead with an 18-year lag

Dependent variable	Independent variable	Coefficient	Standard error	*t*-Value	*p*-Value	R^2	*N*
Murder—6 Nations Combined	Intercept	0.523	0.468	1.12	0.265		
(UK, US, CAN, AUS, NZ, WG)	Preschool Blood Lead	0.192	0.034	5.73	<.0001	0.137	209
Rape—6 Nations Combined	Intercept	−0.052	0.160	−0.32	0.7471		
With County Dummies (not shown)	Preschool Blood Lead	0.114	0.011	10.22	<.0001	0.925	209
USA Murder	Intercept	3.827	0.401	9.54	<.0001		
	Preschool Blood Lead	0.261	0.025	10.34	<.0001	0.723	43
USA Murder with Unemployment Rate	Intercept	2.954	0.592	4.99	<.0001		
	Preschool Blood Lead	0.238	0.027	8.73	<.0001	0.747	43
	Unemployment Rate	0.206	0.106	1.95	0.0582		
Britain Murder	Intercept	0.458	0.064	7.21	<.0001		
	Preschool Blood Lead	0.065	0.006	11.47	<.0001	0.763	43
Britain Murder with Unemployment Rate	Intercept	0.461	0.064	7.17	<.0001		
	Preschool Blood Lead	0.069	0.008	8.16	<.0001	0.764	43
	Unemployment Rate	−0.006	0.011	−0.56	0.5779		
Canada Murder	Intercept	1.280	0.186	6.90	<.0001		
	Preschool Blood Lead	0.056	0.014	4.03	0.0003	0.294	41
Canada Murder with Unemployment Rate	Intercept	1.010	0.205	4.92	<.0001		
	Preschool Blood Lead	0.013	0.022	0.61	0.5425	0.392	41
	Unemployment Rate	0.111	0.045	2.48	0.0177		
Australia Murder	Intercept	2.290	0.159	14.44	<.0001		
	Preschool Blood Lead	−0.020	0.009	−2.21	0.035	0.144	31
Australia Murder with Unemployment Rate	Intercept	2.302	0.154	14.98	<.0001		
	Preschool Blood Lead	−0.040	0.015	−2.74	0.0105	0.226	31
	Unemployment Rate	0.047	0.027	1.72	0.0973		
West German Murder	Intercept	1.361	0.052	26.27	<.0001		
	Preschool Blood Lead	0.002	0.004	0.63	0.5366	0.022	20
West German Murder with Unemployment Rate	Intercept	1.307	0.047	27.93	<.0001		
	Preschool Blood Lead	−0.012	0.006	−2.03	0.0588	0.358	20
	Unemployment Rate	0.050	0.017	2.98	0.0084		
New Zealand Murder	Intercept	−0.583	0.505	−1.15	0.2575		
	Preschool Blood Lead	0.279	0.042	6.63	<.0001	0.603	31

Legend: The best-fit lag for murder is 18 years in regressions combining data across six nations. Unemployment is insignificant. Blood lead is not significant or has an unexpected sign in murder regressions for Australia and West Germany, but blood lead is highly significant in other single-nation regressions for murder with an 18-year lag.

Chicago murder trends also provide anecdotal evidence of a rising percent of murders related to severe gasoline lead exposure. In 1980, 18 years after its 1962 opening beside the Dan Ryan expressway, Robert Taylor Homes accounted for 0.5% of Chicago's population and 11% of Chicago murders (O'Neill, 1997). Hagedorn (2004) argues: "expressways and housing projects concentrated Chicago homicides in Black areas", and illustrates this point by mapping highways against 1965 murder rates, presented beside a picture of Robert Taylor Homes and the Dan Ryan. But lead paint poisoning in late-1940s slums is also consistent with murders near highways in 1965, when children from those slums were youths living near highways built on slum clearance land. Highway air lead then peaked about two decades before Chicago's 1992 murder rate peak. Hagedorn notes: "Murder in Chicago is now more common in the far western and southern areas of the city. Why?" His spatial analysis appears to show 1992 murders tracking expressways to the west and the Dan Ryan south, where the 50% rise in USA per capita gasoline lead use from 1962–1970 spread lead poisoning well beyond the inner city.

4.4. Temporal trends, cross-sectional confounders, and other crime theories revisited

Needleman et al. (2003) found that social factors, including race and single-parents, raised delinquency risk for youths with lower bone lead. Preschool lead exposure is highly correlated with social factors because poor children are more likely to live in older housing with deteriorated paint, and black children were concentrated in cities with higher air lead. Social factors could constitute independent offending risks for those with no preschool lead exposure, and/or interact with lead exposure to increase offending risk, but temporal trends suggest any independent social factor effect is small relative to the lead effect.

The juvenile arrest rate soared in the 1960s, tracking the surge in gas lead after World War II, despite a large 1960s decline in the percent of children in poverty. That rise in juvenile offending coincided with a 1960s rise in the unwed teen birth rate, and the 1990s decline in juvenile arrests coincided with a falling unwed teen birth rate. Higher offending due to single parents would be consistent with juvenile offending that lagged the unwed birth trend by

Table 6
USA central city murder rate regressions

Dependent variable	Independent variable	Coefficient	Standard error	*t*-Value	*p*-Value	R^2	*N*
Central City Murder Rate	Intercept	13.6401	1.4541	9.38	<.0001	0.114	124
	Pop > 1 million	14.7560	4.1127	3.59	0.0005		
	Pop = 250,000–1 million	5.3137	2.1624	2.46	0.0154		
Central City Murder Rate	Intercept	8.6947	2.1164	4.11	<.0001	0.139	124
	LP%	0.0078	0.0018	4.44	<.0001		
Central City Murder Rate	Intercept	2.0444	2.2629	0.90	0.3681	0.329	124
	Pop > 1 million	19.4911	3.6754	5.30	<.0001		
	Pop = 250,000–1 million	7.0711	1.9113	3.70	0.0003		
	LP%	0.0100	0.0016	6.19	<.0001		
Central City Murder Rate	Intercept	6.3635	1.1384	5.59	<.0001	0.608	124
	Pop > 1 million	16.7151	2.7538	6.07	<.0001		
	Pop = 250,000–1 million	4.9510	1.4458	3.42	0.0008		
	Black % of Population	0.0309	0.0025	12.28	<.0001		
Central City Murder Rate	Intercept	1.4088	1.5535	0.91	0.3663	0.688	124
	Pop > 1 million	12.8552	2.5850	4.97	<.0001		
	Pop = 250,000–1 million	4.1694	1.3347	3.12	0.0022		
	LP%	0.0017	0.0013	1.27	0.207		
	Black % Population	60.3729	5.1779	11.66	<.0001		

Legend: These regressions compare average 1985–1994 murder rates across USA cities with differences in circa-1970 childhood lead paint poisoning and air lead exposure. Preschool children in 1970 were in the high murder offense age bracket in 1985–1994. The "LP%" variable measures the percent of each city's 1985–1994 population that had severe childhood lead paint poisoning in 1970. City size dummies were used as indicators of 1970 air lead. City size and LP% are both significant in simple regressions. When LP% and city size are both included, regression R^2 (32.9%) exceeds the variation explained by separate regressions (11.4% + 13.9% = 25.3%) and LP% and city size are more significant (higher *t*-values), reflecting the additive effect of paint and gasoline lead not captured by separate regressions for city size and LP%. When a variable is added for black percent of population, city size is still significant and LP% is not (*t*-value = 1.27), but the LP% coefficient still has the expected sign and retaining LP% in the model increases R^2 to 69%.

12–17 years, as children raised by single mothers became teenagers. The coincident rise and fall of unwed birth rates and juvenile offending is inconsistent with the time-precedence indicator of causation. Nevin (2000) showed age-specific unwed pregnancy rates track USA gas lead trends with time lags consistent with mother's age and lead exposure in the first year of life. Cross-sectional studies that link criminal offending to single parents could reflect separate effects of preschool lead exposure on different types of impulsive behavior, across family generations.

Social trends cannot explain why the 1990s homicide decline was so pronounced among juvenile offenders, and especially black juveniles, but blood lead trends can. Blood lead prevalence over 30 μg/dL among white USA children fell from 2% in 1976–1980 to less than 0.5% in 1988–1991, as prevalence over 30 μg/dL among black children plummeted from 12% to below 1%. The white juvenile murder arrest rate then fell from 6.4 to 2.1 from 1993–2003, as the black juvenile rate fell from 58.6 to 9.7. That 83% fall in the black juvenile murder arrest rate occurred with just 36% of black children living in two-parent families in 1993, and in 2003.

Age-specific arrest rates related to preschool blood lead can explain why crime predictions based on 1990s demographic trends proved inaccurate, and why incarceration and crime both rose prior to 1990 as increased offending by juveniles and young adults more than offset the incapacitation of older offenders. Gun use offers little insight into overall crime trends, but gun homicides did account for most of the 1973–2002 USA murder rate variation. These trends are not inconsistent with the hypothesis that murder is especially affected by severe lead poisoning, but suggest an especially lethal interaction between gun access and severe neurobehavioral damage. This could explain why rural murders fell after 1980 despite easy rural access to guns. The 1990s fall in black juvenile murder arrests coincided with a fall in black youths carrying guns, but blood lead trends could explain why so many black youths stopped carrying guns at the same time.

The black percent of city population appears to explain much of the cross-sectional variation in average 1985–1994 USA central city murder rates, but the 1990s murder rate decline was also led by a sharp decline in offending by blacks in central cities. New York City's racial composition (28% black) also provides no insight into the especially striking decline in that city's murder rate from 31 (per 100,000 population) in 1990 to 7 in 2004. The 2004 murder rate was 20 in Dallas (27% black), 14 in Phoenix (6% black), 13 in Houston (26% black), 13 in Los Angeles (12% black), and 8 in San Antonio (7% black). New York City had extensive slum demolition and reduced incinerator lead emissions in the 1960s, and banned lead paint in 1960, resulting in a large reduction in lead poisoning. New York City children over 60 μg/dL fell from 2694 in 1970 to 494 in 1974, and children over 40 μg/dL fell from 1595 in 1975 to 976 in 1980. New York City and St. Louis both reported about 1200 children per year with blood lead over 30 μg/dL from 1981–1985, when New York's population was 16 times larger. Chicago, Detroit, Baltimore, Philadelphia, and St. Louis report 3–4% of children tested in 1998–1999 had blood lead over 20 μg/dL, but New York City prevalence over 20 μg/dL was just 0.4% (New York City Department of Health, 2002; Missouri Department of Health and Senior Services, 2004; Meyer et al., 2003; US Centers for Disease Control and Prevention, 2005; Maryland Department of the Environment, 2004).

Donohue and Levitt's (2001) theory linking early-1970s abortion legalization to the 1990s USA crime decline highlights the lag between birth and peak offending ages. USA preschool blood lead peaked in the early-1970s, and blood lead trends can explain earlier USA and international crime trends. Donohue and Levitt credit early abortion legalization with early crime declines in New York and California, but state-wide abortion legalization did not presage an early state-wide New York crime decline. That early crime decline was evident only in New York City where there was a pronounced decline in lead poisoning (New York State, 1999, 2004). California also limited gas lead per liter to 0.26 g in 1977 and 0.18 g in 1978, before a national limit of 0.29 g in 1983 (Octel Ltd, 1969–1990). California per capita (leaded) gasoline use was also 30% higher than the rest of the USA in 1950, 20% higher over the 1950s, and 10% higher in the 1960s. California's violent crime rate was then 40% higher than the rest of the USA from 1960–1990, and its burglary rate was 75% higher in the 1960s, 55% higher in the 1970s, and 27% higher in the 1980s (Federal Highway Administration, 2003; US Census, 1975; Bureau of Justice Statistics, 2006).

5. Conclusions

This analysis adds to mounting evidence that preschool lead exposure affects the risk of criminal behavior later in life. Arrest rate shifts and international trends suggest that preschool blood lead especially affects juvenile offending and related trends in index crime (mainly property crime) and burglary. Violent crime trends and shifts to higher adult arrest rates suggest blood lead also affects violent and repeat offending. It is likely that police recorded crime and arrest rate trends examined here also understate the effect that lead had on the 1990s USA crime decline, because crime survey data show an even steeper 1990s violent crime decline, as a larger share of crimes were reported to and recorded by police, and violent crime arrests fell less than police recorded violent crimes, as a larger percent of reported crimes were cleared by arrest (Bureau of Justice Statistics, 2007).

The hypothesis that murder rates are especially affected by severe lead poisoning is consistent with international and racial contrasts and a cross-sectional analysis of average 1985–1994 USA city murder rates. Whether other offending risks are especially related to a blood lead threshold is not known. No threshold is suggested by rising crime that traces back to average preschool blood lead of 5 μg/dL or less in nations where severe poisoning was rare. USA juvenile arrest rates falling through 2003 also show no evidence of a threshold related to historically low late-1980s blood lead. Other research links preschool lead exposure to a wide variety of adverse neurodevelopmental effects including ADHD, other behavioral problems, and IQ losses. Age-specific arrest rates suggest IQ may have only a limited indirect relationship with crime, but evidence of no lower threshold for lead-induced IQ effects warns that there is no lower threshold for neural damage, and no reason to assume that lower blood lead affects IQ and not other manifestations of neural damage, including criminal behavior.

Further research is needed to specify the mechanisms by which blood lead affects behavior, and how blood lead interacts with other risk factors, but policy implications of this study and related research are clear: The association between crime and preschool blood lead should lend urgency to global efforts to eliminate preschool lead exposure. This analysis has focused on gasoline and paint lead as determinants of trends in average preschool blood lead and severe lead poisoning prevalence, but children and pregnant women are also exposed to occupational and secondary lead exposure (lead dust brought home on work clothes), lead in drinking water from old water mains and service line connectors, industrial lead emissions, lead-contaminated toxic waste sites, lead-glazed ceramics, and home remedies and cosmetics in some nations (Rapuano and Florini, 1994). Action is needed to address all these risks. Over 30 nations still use leaded gasoline, and a planned global phase-out by 2008 must be accelerated (United Nations, 2005).

Lead paint hazards are by far the greatest remaining USA lead exposure risk. The actions needed to eliminate such hazards are well known, and hazard reduction costs are more than offset by higher average lifetime earnings resulting from avoided cognitive losses (President's Task Force on Environmental Health Risks and Safety Risks to Children, 2000; US Department of Housing and Urban Development, 1999). A simple window replacement strategy can also yield long-term lead paint hazard reduction plus energy savings from high-efficiency windows that exceed window replacement costs (Jacobs and Nevin, 2006; Nevin and Jacobs, 2006; Nevin et al., 1999). Avoided crime benefits further increase net benefits, and this analysis suggests that further reductions in preschool lead exposure will yield further reductions in crime.

Acknowledgments

The author acknowledges the valuable regression analysis contributions of Artem Gonopolskiy.

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