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Global Benefits From the Phaseout of Leaded Fuel GOING UNLEADED

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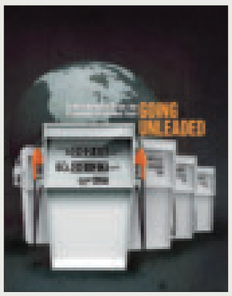

This month's cover reflects the findings of our feature, "Global Benefits From the Phaseout of Leaded Fuel," including a best-estimate global savings of $2.45 trillion and a decrease in average blood lead levels from 17.1 µg/dL to 2.7 µg/dL due to the transition from leaded to unleaded gasoline. The authors point out that environmental health programs have to be financially justified especially in today's tough economic times, so they take data from previous studies that examined the detrimental health effects and costs of lead exposure in the U.S. to estimate the global cost savings of leaded gasoline phaseout.
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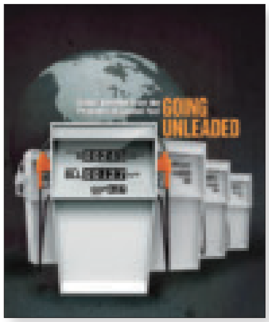

Global Benefits From the Phaseout of Leaded Fuel

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Abstract **The study described in this article assessed the global benefits from the phaseout of leaded fuel. The authors extended previous estimates to the global level and incorporated the latest scientific and economic research on societal effects. Starting with detailed studies in the U.S., the authors argue that extrapolation based on the ratio of U.S. gross domestic product (GDP) to world GDP is the most accurate method at this time. Their overall best estimate is a global benefit of $2.45 trillion/year, within a range of $2.05–$2.83 trillion. Environmental health professionals increasingly face the task of justifying policies on the basis of economic benefits. Without more detailed morbidity and mortality data, the authors' extrapolation here represents the best estimate of global benefits from leaded fuel phaseout. Their estimate adds to the justification of current programs and may help support future international efforts. The authors also comment on how these techniques may be extended to state and local levels.**

Introduction

The phasing out of leaded gasoline has been the single most important strategy in reducing overall lead exposures and lead-induced illnesses, with the economic benefits exceeding costs by more than 10 times (Lovei, 1998). With the introduction of unleaded gasoline, a corresponding drop in blood lead levels (BLL) has been reported all over the world (Clean Air Initiative for Asian Cities, 2006; Environmental Protection Agency Ghana, 2007; Hernandez-Avila, Cortez-Lugo, Munoz, Tellez, & Soliz, 1999; Lovei, 1998; Meyer, McGeehin, & Falk, 2003; Ostro, 1994; Reinhard et al., 2001; von Schirnding, 1999). Leaded gasoline accounted for 80% to 90% of airborne lead in cities where it was used (Lovei, 1999). The U.S. Environmental Protection Agency reported that between 1976 and 1989, the amount of lead used in gasoline was reduced by 99% in the U.S. (U.S. Environmental Protection Agency, 1990). Accordingly, BLL decreased from 17.1 µg/dL in the 1970s to 2.7 µg/dL in the 1990s (Centers for Disease Control and Prevention, 1997; Grosse, Matte, Schwartz, & Jackson, 2002).

The challenge, however, is to estimate the overall *value* of the phaseout campaign. In order to estimate the global savings realized from going unleaded, our strategy was to take the estimated cost savings from existing studies and then multiply by an appropriate factor for the global benefits. The question nevertheless remains, Should the extrapolation factor be based on population, fuel consumption, or gross domestic product (GDP), or simply be indeterminate because it is too controversial or complicated to quantify?

A reasonable first estimate of global benefits has important policy implications, not only for the phaseout of leaded fuel, but undoubtedly for a range of international programs. In the U.S. alone, the sheer magnitude of the phaseout benefits—at over $500 billion per year—demonstrates the importance of undertaking this challenge, even if detailed morbidity and mortality costs are not known across all other nations. Thus, we addressed this challenge by providing valuations based on existing methodologies.

Methods

In the U.S., numerous studies have quantified the negative economic impact from lead. The World Bank has suggested that the experience of phasing out leaded gasoline in the U.S. would have similar benefits in other countries as well (Lovei, 1998). Our first task was to determine the best methodology to convert these costs from the U.S. to the world.

From oil consumption to productivity, we considered various factors to extrapolate from U.S. to global values (Table 1). We arrived at three different comparative approaches: nominal GDP, oil consumption, and population. From these results, a 4.27 extrapolation factor through GDP represented the smallest and most conservative factor. More importantly, GDP represents a culmination of numerous factors that all contribute to the economic output of the individual country and account for the wealth disparity among nations.

At least three fundamental arguments support the critical choice to extrapolate by GDP. First, Hashisho and El-Fadel (2001) applied the methodologies from Schwartz (1994) to quantify the effects of the leaded gasoline phaseout in Lebanon. They extrapolated from the U.S. to Lebanon for cost per incidence by their relative GDP disparity. Thus, a precedent exists for use of this technique.

TABLE **1**

Comparison of Global Extrapolation Factors

Factor	Value
Gross domestic product (GDP) assumptions	
U.S. GDP in 2008 (in millions)	$14,204,322
World GDP in 2008 (in millions)	$60,587,016
U.S. GDP/world GDP	23%
Extrapolation factor for GDP (world/U.S.)	4.27
Oil consumption assumptions	
U.S. barrels per day (bbl/day) in 2008	19,500,000
World bbl/day in 2008	100,210,270
U.S. bbl/day/world bbl/day	19%
Extrapolation factor for oil (world/U.S.)	5.14
Population assumptions	
U.S. population in 2006 (in millions)	299.1
World population in 2006 (in millions)	6,537
U.S. population/world population	5%
Extrapolation factor for population (world/U.S.)	21.85

TABLE **2**

Comparing Gross Domestic Product (GDP) Extrapolation With a Global Estimate of Costs for Dementia

Factor	Cost/Value
U.S. and Canada	$52.62 billion[a]
World	$156.2 billion[a]
U.S. and Canada GDP	$11.716 trillion (World Bank)
World GDP	$36.356 trillion (World Bank)
Extrapolation factor	3.1 = 36.356/11.716[b]
U.S. and Canada benefits	$52.62 billion (Wimo et al., 2006)
World benefits	$163.3 billion = 52.62 x 3.1[b]
U.S. and Canada GDP	$11.874 trillion (International Monetary Fund [IMF])
World GDP	$36.253 trillion (IMF)
Extrapolation factor	3.05 = 36.253/11.874[c]
U.S. and Canada benefits	$52.62 billion (Wimo et al., 2006)
World	$160.7 billion = 52.62 x 3.05[c]

[a]Using the Wimo and co-authors (2006) figures for direct costs of dementia in 2003.

[b]Using the World Bank 2003 GDP figures, our extrapolation method based on GDP disparity yields these results for dementia.

[c]To illustrate the variation in GDP estimates, we used the International Monetary Fund 2003 GDP figures for a similar extrapolation, yielding these results for dementia.

Second, Muir and Zegarac (2001) examined the benefits of lead phaseout *simultaneously* in Canada and the U.S. Since most studies differ due to different time frames, assumptions, and scope of effects included, their study is critical as an independent experiment of whether GDP extrapolation is valid. Muir and Zegarac determined the benefits in 1999 for Canada and the U.S. We independently took their estimated benefits from lead phaseout, and divided by the GDP values for these countries in 1999 to determine the GDP percentage (i.e., benefits/GDP):

- Canada: 20.7/651 = 3.2%
- U.S.: 275/9,216 (low) = 2.98%; 326/9,216 (high) = 3.54%

Canada's benefit as a percentage of its GDP is within the range of the U.S. benefit as a percentage of its GDP. Thus, the benefits of lead phaseout in the U.S. can reasonably be extrapolated to Canada by relative GDP values.

Third, Wimo and co-authors (2006) calculated the *global* cost for dementia and argued that "from macroeconomic research, it is well known that there is a strong correlation between expenditures on health care per capita and the GDP per capita (Wimo, Jonsson, & Winblad, 2006)." Wimo and co-authors further argued, "Differences in GDP per capita also reflect differences in care resources (e.g., countries with a high GDP per capita and year have more costly caring resources, such as long-term care, than countries with low GDP per capita)."

While the effects of dementia and IQ decrement are not identical, they have enough fundamental similarities to lend support to this method of extrapolation. Besides direct health care costs, dementia is expected to have substantial effects on forgone personal income and tax revenue shortfalls. Wimo and co-authors (2006) argued, "The cost of the illness due to a disease in question is equal to the value of what these resources would have produced if there had been no cases of the illness, i.e., opportunity costs." They presented the following equation:

Direct cost (country A) = direct cost
per demented (key countries)
x
(GDP country A/GDP key countries)
x prevalence (country A).

Using either World Bank or International Monetary Fund GDP figures, our extrapolated results from Table 2 of $163.3 billion and $160.7 billion were very close to $156.2 billion for the global cost of dementia calculated by Wimo and co-authors (2006). The minor difference is that we extrapolated from the U.S. directly to total world costs, whereas Wimo and co-authors calculated individual country costs and then arrived at the total world costs. In countries where the cost of dementia is not easily quantifiable, Wimo and co-authors relied heavily on GDP disparity between the key country and target country to extrapolate costs. They also cited previous works by Gerdtham and Löthgren (2000) and others who found that "health expenditures and GDP are cointegrated, the fraction of expenditure devoted to health care of total GDP increases with GDP (Wimo et al., 2006)." Since the U.S. represented a disproportionately large percentage of the world GDP in their study, the resultant world benefit of $2.45 trillion minimized errors in extrapolation.

From the three previous arguments, it is clear that GDP is not only the best choice for extrapolation at this time but in fact has already been applied to global values for other health impacts.

Our next major task was to review diverse studies to arrive at a best estimate for global benefits. For example, Schwartz (1994) represents one of the earliest attempts to quantify the benefits of reduced BLL in a comprehensive way. More specifically, he quantified how reduced BLL would benefit American adults and children in 1987 U.S. dollars. His total annual amount was $17.55 billion per 1 µg/dL.

In 1999 U.S. dollars, Muir and Zegarac (2001) estimated the income loss due to five IQ points decrement as $275 to $326 billion annually in the U.S. Furthermore, they quantified the adverse economic impacts on residual GDP growth as $17.1 to $85 billion through negative technical change and contribution of human capital from IQ decrement. Muir and Zegarac also quantified, from three IQ points decrement, other societal effects such as low birth rate ($1.17 billion) and male incarceration ($8.2 billion) annually.

The work of Grosse and co-authors (2002) is critical to our analysis, because they measured the actual decline in BLL from 1976 to 1999 in American children as 15.1 µg/dL. They incorporated this information with updated economic estimates to calculate the annual benefits from preventing IQ decrement at $110–$319 billion in 2000 U.S. dollars.

In addition to the earnings loss from IQ degradation ($165–$233 billion) and health care costs ($11–$53 million), Gould (2009) expanded the analysis for children by including special education ($30–$146 million) and attention deficit hyperactivity disorder (ADHD) at $198 million. Moreover, Gould addressed societal impacts from lead, including crime ($1.76 billion) and tax revenue forgone ($25–$35 billion). Gould presented the annual BLL benefits for children as $192 to $270 billion per year.

In reviewing this literature, it becomes clear that researchers have concentrated on different aspects of lead poisoning as an environmental pollutant. For example, some researchers concentrated on the adverse effects on children. Others began to analyze beyond individuals and quantified societal effects as causal studies have evolved. Therefore, to understand the overall effects, our next task had to synthesize not only the direct effects on individuals, but more importantly, the growing evidence of

TABLE **3**

Individual Costs, Adults and Children (Schwartz, 1994)

Factor	Value
Total cost for children and adults in 1987 U.S. dollars minus the discounted life earnings for children per 1 µg/dL reduction in blood lead levels (BLL)	$12,492,000,000
Inflation rate of 1.25% over 23 years to 2010 U.S. dollars	$(1.0125)^{23}$
BLL reduction from phaseout, 1976–1999 (Grosse et al., 2002)	15.1 µg/dL
Gross domestic product (GDP) of world/GDP of U.S.	4.27
$12,492,000,000*(1.0125)^{23}*15.1*4.27$	$1.07 trillion

TABLE **4**

Costs Associated With a Three IQ Point Degradation (Muir & Zegarac, 2001)

Factor	Value
Low birth rate	
Low birth rate cost	$1,170,000,000
Inflation rate of 1.25% over 11 years to 2010 U.S. dollars	$(1.0125)^{11}$
Gross domestic product (GDP) of world/GDP of U.S.	4.27
$1,170,000,000*(1.0125)^{11}*4.27$	$5.7 billion
Male incarceration	
Male incarceration cost	$8,230,000,000
Inflation rate of 1.25% over 11 years to 2010 U.S. dollars	$(1.0125)^{11}$
GDP of world/GDP of U.S.	4.27
$8,230,000,000*(1.0125)^{11}*4.27$	$40.3 billion
Residual contribution to GDP	
Residual contribution forgone in U.S. GDP growth from IQ degradation	$5,100,000,000
Inflation rate of 1.25% over 11 years to 2010 U.S. dollars	$(1.0125)^{11}$
GDP of world/GDP of U.S.	4.27
$5,100,000,000*(1.0125)^{11}*4.27$	$25 billion

TABLE **5**

Discounted Earnings per Cohort of Children (Grosse et al., 2002)

Factor	Value
Discounted earnings for two-year-old cohort in 2000	$723,300
Inflation rate of 1.25% over 10 years to 2010 U.S. dollars	$(1.0125)^{10}$
IQ-blood lead level (BLL) slope	0.257
Earnings slope of 2%	0.02
Annual cohort size of children affected	3,800,000
BLL reduction from phaseout, 1976–1999	15.1 µg/dL
Gross domestic product (GDP) of world/GDP of U.S.	4.27
$723,300*(1.0125)^{10}*0.257*0.02*3,800,000*15.1*4.27$	$1.03 trillion

TABLE **6**

Costs of Lead From Taxes Forgone, Attention Deficit Hyperactivity Disorder (ADHD), and Lead-Linked Crime (Gould, 2009)

Factor	Value
Tax revenue forgone	
Earnings forgone per µg/dL blood lead level (BLL) (Grosse et al., 2002)	$14,127,495,600
Inflation rate of 1.25% over 10 years to 2010 U.S. dollars	$(1.0125)^{10}$
Tax revenue percentage	15%
BLL reduction from phaseout, 1976–1999 (Grosse et al., 2002)	15.1 µg/dL
Gross domestic product (GDP) of world/GDP of U.S.	4.27
$14,127,495,600*(1.0125)^{10}*0.15*15.1*4.27$	$154.7 billion
ADHD	
Number of ADHD cases due to lead	$290,000
Cost per ADHD case in 2006	$684
Inflation rate of 1.25% over four years to 2010 U.S. dollars	$(1.0125)^4$
GDP of world/GDP of U.S.	4.27
$290,000*684*(1.0125)^4*4.27$	$890 million
Lead-linked crimes	
Costs of lead-linked burglaries	116,541 at $4,010 per case
Costs of lead-linked robberies	2,499 at $22,871 per case
Costs of lead-linked assaults	53,904 at $20,363 per case
Costs of lead-linked rapes	4,186 at $28,415 per case
Costs of lead-linked murders	717 at $31,110 per case
BLL reduction from phaseout, 1976–1999 (Grosse et al., 2002)	15.1 µg/dL
Inflation rate of 1.25% over four years to 2010 U.S. dollars	$(1.0125)^4$
GDP of world/GDP of U.S.	4.27
$([116,541*4,010] + [2,499*22,871] + [53,904*20,363] + [4,186*28,415] + [717*31,110])*15.1*(1.0125)^4*4.27$	$119.5 billion

societal effects. The equation used to calculate global benefits is summarized below.

Total global benefits: B = (GDP of the world/GDP of U.S.)*(Ch + Ad + Cr + Tx + Rs + So)

where

Ch (child) = morbidity, mortality, discounted earnings forgone, and ADHD,

Ad (adult) = morbidity and mortality,

Cr = crime,

Tx = tax revenue forgone from discounted earnings shortfall,

Rs = total residual GDP increase forgone, and

So = societal costs due to IQ decrease.

We started with the assumptions of 1.25% annual inflation, BLL reduction of 15.1 µg/dL, and a U.S.-to-world extrapolation factor through GDP of 4.27.

While it is difficult to assign upper and lower limits to this multifaceted global estimate, insights can be gained by examining alternate measures. For example, we can approximate an upper limit for global benefits by using the GDP figures represented as purchasing power parity (PPP). The World Bank presented the figures for 2008 GDP in PPP as "an international dollar has the same purchasing power over GDP as a U.S. dollar has in the United States."

- U.S.: $14,093,310,000
- World: $69,609,169,000

To approximate a lower limit, we can use a segment of GDP. An alternate measure comes from the argument that the overall contribution of labor to GDP is country dependent. Certain countries are more dependent on their labor force's intellectual productivity while others are more dependent on their resource extraction industries. We can take this into account by using per capita consumption (Garber & Phelps, 1997). Household consumption accounts for more than 60% of all impacts of consumption (Hertwich et al., 2010). Using the World Bank's database for Household Family Consumption Expenditure (HFCE) in 2005 expressed in PPP, we can extrapolate global benefits from the U.S. to the world.

- U.S. HFCE: $8,694,100,000,000
- World HFCE: $31,119,476,506,067

Results

To arrive at our best estimate of global benefits, we started with Schwartz (1994) for children and adult costs minus discounted life earnings for children, and arrived at $1.07 trillion/year (Table 3).

To include the additional costs of low birth rate, male incarceration, and residual contribution of GDP, we added the costs associated with a three-IQ-point degradation presented in Muir and Zegarac (2001) for a total of $71 billion/year (Table 4).

To include the global cost for children through IQ decrement, we added $1.03 trillion/year from Grosse and co-authors (2002) (Table 5).

To incorporate global benefits for children and adults from societal and individual effects, we added $275 billion/year from Gould (2009) on taxes forgone, ADHD, and lead-linked crime (Table 6).

We can then sum all of the previous components (in billions) for a best estimate of global benefits (Table 7):

1,070 + 5.7 + 40.3 + 25 + 1,030 + 154.7 + 0.89 + 119.5 = $2.45 trillion/year.

If we divide each component by the extrapolation factor of 4.27, we can estimate the benefits of phasing out leaded fuel in the United States:

251 + 1.34 + 9.44 + 5.85 + 242 + 36.2 + 0.21 + 28.0 = $574 billion/year for U.S.

For a lower-limit estimate, the global annual benefits using HFCE are as follows:

Extrapolation factor: 3.58 = $31,119,476,506,067/$8,694,100,000,000,
and
3.58*$574 billion = $2.05 trillion/year,
where
$574 billion = annual benefits for U.S. alone through best-estimate calculation.

For an upper-limit estimate, the global annual benefits in PPP are as follows:

Extrapolation factor: 4.94 = $69,609,169,000/$14,093,310,000,
and
4.94*$574 billion = $2.83 trillion/year,
where
$574 billion = annual benefits for U.S. alone through best-estimate calculation.

TABLE **7**

Best Estimate for Global Benefits in U.S. Dollars per Year (in Billions)

Factor	Value
Individual costs, adults and children (Schwartz, 1994)	1070
Low birth rate (Muir & Zegarac, 2001)	5.7
Male incarceration (Muir & Zegarac, 2001)	40.3
Residual contributions (Muir & Zegarac, 2001)	25
Discounted earnings from children (Grosse et al., 2002)	1030
Taxes forgone (Gould, 2009)	154.7
ADHD (Gould, 2009)	0.89
Lead-linked crime (Gould, 2009)	119.5
Total U.S. dollars per year (in trillions)	2.45
Or	
Total costs in U.S. only (Schwartz, 1994; Muir & Zegarac, 2001; Grosse et al., 2002; Gould, 2009)	5735
Gross domestic product (GDP) of world/GDP of U.S.	4.27
Total U.S. dollars per year: 5735 x 4.27 (in trillions)	2.45

Discussion and Conclusion

With IQ decrement, studies show the earnings slope of 2% is actually closer to 1% (Gayer & Hahn, 2006; Zax & Rees, 2002). At the same time, more recent research shows that the IQ-BLL slope is much higher than previously estimated, at approximately 0.46 (Canfield et al., 2003). This is due to adverse health effects of lead at low levels previously thought safe. Taking these developments together, if the earnings slope is halved while the IQ-BLL slope is doubled, we assume the net result essentially remains the same.

Three additional effects suggest that our estimate is conservative: unknown health effects, urbanization effects, and information effects. First, previous estimates do not account for other suspected health effects from lead exposures that are not yet quantifiable. These include hearing loss, cancer, reduced growth rate/stature, pain and suffering from medical treatment, and additional neurological disorders that affect social and economic disparity (Heckman, 2008; Munter, Menke, DeSalvo, Rabito, & Batuman, 2005; Needleman, Riess, Tobin, Biesecker, & Greenhouse, 1996; Schwartz, 1994; Sciarillo, Alexander, & Farrell, 1992). In addition, various societal effects have been directly linked to lead but have not been monetized. These include poverty during the first three years of life, out-of-wedlock births, welfare collection, high-school dropouts, and poverty rates (Muir & Zegarac, 2001). As new information becomes available on these effects, the estimated benefits will only increase.

Second, the global population is becoming increasingly urbanized. The effects from leaded fuel are worse in urban areas, where automobile use is more concentrated. Thus, the urbanization effect is likely to increase the estimated benefits from phasing out leaded fuel (Lovei, 1998; World Bank, 2001).

Third, the modern world is largely an information economy. In emerging economies, as information is becoming more easily accessed (e.g., broadband access to the Internet), the ability to process and apply information through cognitive (e.g., IQ) and noncognitive (e.g., ADHD) means is fundamental to a country's economic growth. Thus, the benefits from the phaseout of leaded fuel are likely to increase as emerging economies become more dependent on the use of information. This is difficult to quantify, but we know that it must increase the estimated benefits from phasing out leaded fuel.

In the absence of actual morbidity and mortality rates along with detailed localized costs for every nation, our extrapolation equation serves as a best estimate for the benefits of unleaded gasoline thus far. The sheer magnitude of the $2.45 trillion/year figure underscores the importance of this task. The toxicity of lead affects every nation, whether it has a developed or developing economy.

We know from existing studies that the aggregated benefits for the U.S. alone total well over $500 billion per year. Our analysis extends that understanding by demonstrating that the phaseout can have significant effects on GDP: the global monetary benefits are on the order of trillions of dollars per year, ranging from $2.05 to $2.83 trillion.

In addition, we can interpolate to state and local levels when detailed incidence and cost per incidence rates are not readily available. In the case of California, for example, its GDP in 2008 was about 13.3% of the U.S. GDP (Bureau of Economic Analysis, 2010). In the absence of detailed regional data, the estimated benefit for California would be 13.3% x $574 billion, or $77 billion/year. In 2009–2010, California spent $70.3 billion on health and social services departments and entities (Legislative Analyst's Office, 2010). In comparison, the phaseout of leaded fuel alone yields greater benefits each year. These interpolated benefits will certainly not resolve every budget debate, but they bring a missing context to the budgeting of preventative programs.

Substantial uncertainties remain regarding global benefits, which are not entirely surprising given the complex effects of lead. Scientific as well as economic research should continue to refine our estimates of benefits. As recent studies have shown, for example, lead not only affects individuals but society as a whole. With the introduction of each generation, we expect the cumulative benefits to grow well beyond our original estimates.

We suspect that the techniques employed in our study may be applied to other environmental agents. Indeed, they already have been employed with conditions such as dementia. While inevitable uncertainties exist with such studies, the sheer magnitude of the benefits underscores the critical role of these studies in helping to shape appropriate policies and provide stronger advocacy for continued scientific research.

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