# Societal Costs of Exposure to Toxic Substances: Economic and Health Costs of Four Case Studies That Are Candidates for Environmental Causation

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Four outcomes that evidence suggests are candidates for "environmental causation" were chosen for analysis: diabetes, Parkinson's disease (PD), neurodevelopmental effects and hypothyroidism, and deficits in intelligence quotient (IQ). These are an enormous burden in the United States, Canada, and other industrial countries. We review findings on actual social and economic costs, construct estimates of some of the costs from pertinent sources, and provide several hypothetical examples consistent with published evidence. Many detailed costs are estimated, but these are fragmented and missing in coverage and jurisdiction. Nonetheless, the cumulative costs identified are very large, totaling $568 billion to $793 billion per year for Canada and the United States combined. Partial Canadian costs alone are $46 billion to $52 billion per year. Specifics include diabetes (United States and Canada), $128 billion per year; PD in the United States, $13 billion to $28.5 billion per year; neurodevelopmental deficits and hypothroidism are endemic and, including estimates of costs of childhood disorders that evidence suggests are linked, amount to $81.5 billion to $167 billion per year for the United States and $2 billion per year in Ontario; loss of 5 IQ points cost $30 billion per year in Canada and $275 billion to $326 billion per year in the United States; and hypothetical dynamic economic impacts cost another $19 billion to $92 billion per year for the United States and Canada combined. Reasoned arguments based on the weight of evidence can support the hypothesis that at least 10%, up to 50% of these costs are environmentally induced—between $57 billion and $397 billion per year. *Key words:* diabetes, environmental disease, healthcare, hypothyroidism, IQ loss, neurodevelopmental deficits, Parkinson's disease, societal and economic costs. — *Environ Health Perspect* 109(suppl 6):885–903 (2001).
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Within the last few years a substantial amount of literature has been published of both evidence and argument concerning real injury and serious threats to human health from exposures to toxic substances and persistent toxic substances. These publications have emerged in fairly rapid succession from independent scientists, government agencies, and nongovernment public interest groups (*1–11*).

The most recent of these studies focused on the implications of environmental contaminants, particularly neurotoxic chemicals, for children's development and health. Researchers realize that children are not just "little adults," and the studies suggest that the developing fetus, infant, and child are particularly vulnerable to the toxic effects of chemicals. Together with emerging evidence that developmental disabilities are common in North American children, affecting millions, this new evidence has created a new area of public health concern and science.

With this information as a backdrop, the International Joint Commission's (IJC) Great Lakes Science Advisory Board, Workgroup on Ecosystem Health (SAB-WGEH), selected several of the effects or outcomes, suggested by the research results as candidates for environmental causation, for analysis from the societal and economic perspectives. In this light, several things should be noted at the outset. First, the chosen case studies are based on the collective professional judgment of the SAB-WGEH, as people knowledgeable of the scientific background and evidence on human exposure to many toxic and persistent toxic substances, on mechanisms of action, experimental work, effects in wildlife, environmental etiology, and other studies that suggest that environmental agents cause clinical disease in humans and that children are at particular risk.

Second, this report must be seen within the context of the workshop as a whole, which covered several of the case studies in greater detail. Thus, this report takes those case studies as givens and, aside from selected references consulted to show how certain chosen effects may be linked and to motivate some of the analysis, it is beyond the scope of this report to report a full review of the evidence.

Third, this report makes no definite attribution of any of the case-study effects to any particular environmental toxic substance, persistent toxic substance, or other pollutant or agent. However, a great many toxic and possibly neurotoxic agents circulate freely in the environment; all people and potential progeny are constantly exposed to these complex mixtures and have been for many decades, making it neither reasonable nor prudent to assume a cumulative zero effect on the human population.

Also, this article makes no specific, analytical determination of the proportion of these case-study effects or diseases and their health and economic costs that may be explained by environmental or other causes. Rather, reasonable and alternative hypotheses are made about these proportions solely to illustrate the potential societal and economic costs, consequences, and significance. The focus on the economic and societal dimensions of health costs is highly relevant because these costs are an enormous and growing financial burden on society.

The selected case-study effects include diabetes; neurotoxicity presented as Parkinson's disease (PD); neurodevelopmental effects in children, with consideration of hypothyroidism as one possible mechanism of causation; and neurodevelopmental effects on the intelligence quotient (IQ). Where possible, costs associated with sequelae possibly related to neurodevelopmental effects and hypothroidism or other neurotoxic mechanisms, such as autism, attention deficit-hyperactivity disorder (ADHD), dyslexia, and violent behavior are also covered. These effects or outcomes reflect that children grow up to be adults, that some effects do not appear until later in life, and that some subpopulations are at higher risk than others.

## Methods and Materials

The methods used involve the examination of several lines of evidence, including empirical, methodological, and theoretical. First, the literature was reviewed to determine the evidence leading to the published concerns that exposures to environmental agents, particularly persistent toxic substances, are plausible

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risk factors in children, and the chosen effects or outcomes.

Second, literature was reviewed to gauge and assess the extent to which approaches and methodologies to measure such financial and economic costs and impacts, in general, are developed, and the extent to which case studies on our chosen outcomes have been undertaken. Where such methodologies and case studies existed, they were either cited, adapted, updated, or expanded.

Third, where no existing studies were found that evaluate or analyze cost for any of the selected effects, primary data sources were searched for, and where possible, estimates were made using the existing methodologies and/or economic theory.

Throughout this exercise, efforts were made to develop independent estimates for Canada or Canadian jurisdictions, and the United States. In some cases, cost estimates for other countries are reported in the literature, and these are cited here for comparison.

## Results—General

This section is intended to provide an overview of the most general and preliminary findings of this study and to provide some context for the motivation behind the work. In general, the literature describing approaches and methodologies to estimate the societal and economic costs of illness and disease and the counterpart estimation of the public health benefits of reducing or eliminating exposure to toxic agents is well developed (*12–17*). However, the application of these tools to actually describe such costs, and to value such benefits, is limited.

Reducing or eliminating exposures costs money, so people continue to be exposed. However, maintaining exposures also has its costs; but it is more difficult and expensive to measure them, albeit some attempts have been made in certain instances, for example, with lead (*13,17,18*) and, more recently, with air pollution (*16*). In the Great Lakes region, there is no systematic and comprehensive effort to estimate the costs of the effects on human health of exposures to toxic substances or persistent toxic substances.

The emergent evidence and the resulting concerns expressed in the literature by both government and nongovernment bodies and agencies, and by scientists, can be seen, together with data on the costs of health care in Canada and the United States. The evidence of injury and the healthcare and economic costs correlate with and reflect each other. However, as an indicator of damage, medical expenditures are only a proxy measure that underestimates the value of avoiding an illness or preventing a disease.

In the United States, actual national health expenditures (public and private) totaled almost \$1.1 trillion in 1997 (\$1.276 trillion in 1999 dollars), or almost \$4,000 (\$4,640 in 1999 dollars) per person, and 13.5% of the gross domestic product (GDP). These expenditures are projected to total \$2.2 trillion by 2008, or almost \$7,200 per person, and 16.2% of GDP (*19*).

In Canada, actual national health expenditures (public and private) totaled almost \$77 billion in 1997, or just over \$2,500 per person, and 8.9% of GDP. These expenditures in 1999 amounted to about \$86 billion, or more than \$2,800 per person, and 9.2% of GDP (*20*).

In Ontario, the 1994 total health expenditure was almost \$28.5 billion, or about \$2,600 per person. Ontario's expenditure is forecast almost \$3,000 per person in 1999 (*20*).

These very large costs of healthcare vividly underline the importance of considering them in the context of environmentally caused disease and the need to consider the linkages between disease prevention and pollution prevention, reduction, and elimination. However, as noted above, these proxy measures are inadequate in themselves, as they are usually large underestimates of the true value of avoiding illness or preventing disease (*17*).

Merely taking account of these direct costs of illness does not adequately tally the economic costs and consequences. Other costs are incurred in addition to those from direct medical intervention, and from the viewpoint of the economic value of avoiding disease, or maintaining health, people may indicate a willingness to pay in excess of the direct medical costs (*12,14,16*).

Other direct expenditures also include those that are nonmedical, such as food, transportation, lodging and institutional care, compensatory educational costs, family care and in-home education, home aids, and clothing. Another category of costs includes other economic, financial, personal, and social impacts and costs that are equally important although indirect.

Indirect costs are those that occur because of loss of human potential or loss of life or livelihood due to sickness, disability, or death. Such costs may occur because of decreased earning ability when working, or because of long-term disability that necessitates a change in type of work, or even the inability to work altogether. For example, these may be related to a decrease in productivity due to absence from work or they may be related to decreased earnings potential because of potential disabilities, lost earnings due to premature mortality, and increased insurance costs.

Other intangible costs, even though difficult to measure, are real nonetheless. These include the costs of pain and suffering, dread and the type of death, grief, loss of quality and enjoyment of life, loss of life years, loss of companionship and social contact, and other nonfinancial outcomes of disease and medical care, including side effects of medication.

We can use some economic techniques or tools in our attempt to value many but perhaps not all of these costs and losses. These tools include accounting for lost earnings or income, for the costs of averting behavior or defensive expenditures, and for compensatory wages or wage differentials. These tools rely on market-based prices and personal actions that can be readily measured and that are familiar to people.

Other tools, which do not use the so-called revealed preferences of market-based signals and prices, rely on surveys that attempt to elicit so-called stated preferences.These try to measure what people state they would be willing to pay to avoid an illness or disease (or more frequently, a small increase in the risk of an illness or disease), or what they say they would be willing to accept in compensation for an illness or disease or a small increase in the risk of said condition. These survey-based techniques or tools of valuation are known as contingent valuation analysis and conjoint analysis. They have been used in Canada to value the health effects of air pollution (*16*), and there have been other applications not referenced here. It would be interesting to ask what people are willing to pay to avoid, or what they are willing to accept in compensation for having, a child who is neurodevelopmentally disabled.

To summarize the general results, the concerns about the effects on human health of exposures to toxic substances and persistent toxic substances are substantively based on the weight of evidence and on the emerging science. In addition, the overall or total health expenditures incurred in both Canada and the United States are an enormous and substantially growing burden. These societal costs directly reflect a disease burden in both adults and children and are thought to contain an unknown component with environmental causation as a hypothetical candidate, since known risk factors cannot account for it.

While this basic conclusion has been variously stated in several reports and scientific publications, it is perhaps best put in a recent (June 2000) scientific publication of the U.S. Public Health Service, National Institutes of Health, which states,

> An association has been found between exposure to toxic chemicals and various neuro-developmental disorders such as learning disabilities, intellectual retardation, dyslexia, attention deficit/hyperactivity disorder, autism, and propensity to violence. Timing of exposure can be critical to the development of these disorders that currently affect millions of children. (*21*)

It is also evident that the tools and techniques to estimate the societal and economic costs and impacts of environmental disease exist, have been used in a number of instances, and have a large potential in other applications.

## Results—Case Studies

### Diabetes

Diabetes mellitus is a chronic and potentially disabling disease that represents a major public health and clinical concern. It is a major source of morbidity, mortality, and economic expense in both the United States and Canada, as well as in other industrial countries (*22–29*).

People with diabetes are at increased risk for chronic complications specific to the disease, including cardiovascular disease, stroke, high blood pressure, lower limb amputations, kidney disease, eye disease (blindness), peripheral neuropathy, and other general medical conditions. Consequently, people with diabetes have more frequent and intensive encounters with the health care system (*22,25*).

In 1997, an estimated 10.3 million Americans reported they had diabetes and about 5.4 million have undiagnosed diabetes. Some uncertainty exists about these prevalence estimates, with suggestions that the disease could affect as much as 10% of the population. Other reports indicate higher rates up to 20% in people 50 years of age or older, with even higher rates in native North Americans, many people of Asian descent, and blacks (*22,25*).

In Canada, estimates of prevalence rates are similar, with similar uncertainties. On the basis of the 1996/1997 survey data and extrapolation of American data, the prevalence of diagnosed diabetes in Canada is 3.2% of the population over 12 years of age, or almost 800,000 people; including undiagnosed cases brings the total to 4.9–5.8% of the population over 12 years of age, or 1.2 million to 1.4 million people (*25*).

Other estimates put diagnosed diabetes at 4.5% (1.3 million), and 5% (1.5 million) of Canadians (*30*). Depending on the report consulted, anywhere from another 50–100% of the diagnosed cases may be matched by an undiagnosed case.

On the basis of the 1996/1997 survey data, native North Americans in Canada have triple the age-adjusted prevalence rate found in the general population, or about 60,000 cases, including undiagnosed (*25*).

Prospects for the future are not good. As the population as a whole ages, the prevalence will reflect this and is expected to increase in Canada to about 3 million by 2010 (*30*). Specific projections for the United States were not found in this review; however, it is expected to be similar to Canada's, and the World Health Organization estimates a doubling of world prevalence of diabetes by 2010 (*30*).

Some might argue that the increase in incidence or prevalence that accompanies the aging of the population is not an environmental effect. However, that argument raises questions, and it seems prudent to allow for the possibility that the age-specific incidence rates (the annual number of new cases), and therefore the prevalence or total number of cases could increase in the future because of environmental causes. That is the implicit intent here in referring to projections of the future: the burden of the disease is expected to become heavier, and this can mask environmental effects.

For example, we do not know how long an environmental effect might take to be expressed in clinical disease—a possible latency—and it is possible that older people are more susceptible to environmental effects. In other words, it does not seem reasonable to assert that there is absolutely no environmental effect component in the increases in incidence or prevalence that might appear as the population ages.

***Economic cost—case study.*** *United States.* For this review we located several studies that demonstrate methods and estimate the economic burden for several jurisdictions. The most pertinent, complete, and up-to-date is a 1998 report from the American Diabetes Association (ADA), which estimates the direct medical and indirect expenditures attributable to diabetes in 1997 for the United States (*22*).

The methodology is consistent with other cost-of-illness studies in which the economic costs consist of healthcare expenditures and the value (measured as foregone earnings) of productivity lost due to disability and premature death. The direct medical costs consisted of two components: the first includes medical expenses attributed to diabetes without complications, and to acute metabolic conditions due to diabetes; the second includes the attributable expenditures associated with the excess prevalence of chronic complications of diabetes, and with the excess prevalence of general medical conditions, among people with diabetes.

Table 1 provides details about the healthcare expenditures attributable to diabetes by various factors, as reported by the ADA (*22*). Table 2 provides data on the total attributable economic costs, including the foregone productivity measures based on lost earnings due to disability and death.

The results reveal the following: Total direct medical and indirect expenditures (including the value of lost productivity) attributable to diabetes in 1997 were estimated at $98 billion. Updating these costs from 1997 to 1999 dollars, using the Medical Care component of the U.S. Consumer Price Index, involves an inflation factor of 1.16 (*31*), which would bring the total to $113.7 billion.

**Table 1.** Health care expenditures attributed to diabetes by age, race, condition, and type of service, 1997, in millions of 1999 U.S. dollars.[a,b]

| Medical condition | Inpatient hospital | All outpatient | Nursing home, home healthcare, and hospice | Total direct medical expenditures |
|---|---|---|---|---|
| Uncomplicated diabetes and acute metabolic conditions | 3,347 | 3,522 | 2,039 | 8,908 |
| Excess prevalence of related chronic complications[c] | 11,295 | 833 | 1,597 | 13,736 |
| General medical conditions | 17,205 | 8,278 | 3,073 | 28,556 |
| Total cost | 31,847 | 12,632 | 6,709 | 51,200 |
| Age and race | | | | |
| <45 | 2,915 | 1,775 | 41 | 4,731 |
| <65, nonwhite | 4,312 | 1,537 | 124 | 5,973 |
| <65, white | 6,941 | 3,867 | 176 | 10,986 |
| ≥65, nonwhite | 4,943 | 1,099 | 1,029 | 7,070 |
| ≥65, white | 15,650 | 3,611 | 5,387 | 24,648 |

Note: Numbers may not sum because of rounding.
[a]All data in this table are indexed using the medical component of the U.S. Consumer Price Index. [b]This table is a modification of Table 6, "Healthcare expenditures attributable to diabetes by age, race, condition, and type of service," in reference (*22*). [c]Related chronic complications include neurologic disease, peripheral vascular disease, cardiovascular disease, renal disease, ophthalmic disease, and other chronic complications.

**Table 2.** Total economic costs of diabetes by age and race, 1997, in millions of 1999 U.S. dollars.[a,b]

| Age, race | Direct medical expenditures | Lost productivity | Total cost |
|---|---|---|---|
| <45, all | 4,731 | 5,868 | 10,599 |
| <65, all | 16,988 | 57,143 | 74,131 |
| <65, white | 10,986 | 11,598 | 22,584 |
| <65, nonwhite | 7,368 | 4,174 | 11,542 |
| ≥65, all | 31,756 | 5,516 | 37,272 |
| ≥65, white | 24,648 | 3,340 | 27,987 |
| ≥65, nonwhite | 7,070 | 567 | 7,637 |
| Total | 51,200 | 62,645 | 113,856 |

[a]All data in this table are indexed using the medical component of the U.S. Consumer Price Index. [b]This table is a modification of Table 7, "Attributable economic cost of diabetes,"in reference (*22*).

Direct medical expenditures alone totaled $51.2 billion in 1999 dollars. This amount was composed of $8.93 billion for diabetes and acute glycemic care; $13.69 billion because of excess prevalence of related chronic complications; and $28.54 billion because of the excess prevalence of general medical conditions. Two-thirds of all medical costs were attributable to elderly people (>65 years of age).

Table 2 shows that attributable indirect costs totaled $62.65 billion. This consisted of $19.66 billion resulting from premature mortality and $42.98 billion from disability (numbers are rounded).

Total medical expenditures (inflated to 1999 U.S. dollars) incurred by people with diabetes totaled $90.13 billion, or $11,682 per capita, compared with $3,096 for people without diabetes (*22*). It is clear that the economic burden of diabetes in the United States is immense.

*Canada.* There was no comprehensive economic costs study similar to the ADA report available for Canada. A 1999 report by Health Canada (*25*), made only passing mention to the economic burden of diabetes, referring to only one incomplete study of the Canadian experience, and then referred to and extrapolated the work of the ADA cited above.

The incomplete study cited estimated that the burden of diabetes medical care alone was about $1.1 billion annually in 1993 (*25*). Updating the cost from 1993 to 1999 dollars, using the Health and Personal Care component of the Canadian Consumer Price Index, involves an inflation factor of 1.075 (*32*), and this would bring the total to $1.18 billion Canadian dollars. The study was termed incomplete because none of the excess prevalence of complications closely tied to diabetes, or of the excess prevalence of general medical conditions among diabetics, or of the lost productivity due to morbidity and mortality, were included.

Because the data for Canada on prevalence, hospital and medical care utilization, and associated morbidity and mortality, roughly parallel the situation in the United States, the Health Canada study scaled the U.S. economic cost estimates in proportion to the population (Canadian population is approximately one tenth that of the United States). Thus, the costs in Canada may be as high as 10% of the costs identified above for the United States, or about $14.157 billion (1999 CDN dollars) annually, in total. This includes Canadian exchange rate adjustment to the 1997 U.S. cost and then inflation to 1999 dollars.

Data on patient visits to physicians in Canada in 1999 indicate that diabetes was the second leading diagnosis, behind hypertension, and followed by depression. Prescription drugs dispensed for diabetes ranked in 11th place in 1999, totaling almost 9 million prescriptions (*33*).

*Ontario.* The Universal Health Care system in Canada, or Medicare, provides that each province in Canada administer the delivery of covered health care in its own jurisdiction. In Ontario, this is known as the Ontario Health Insurance Plan (OHIP). In Ontario, data on hospital usage by detailed medical code were published annually in a report until the 1991/1992 edition, when the report was discontinued.

Recourse was made to special requests to the Health Planning Branch of the Ontario Ministry of Health (*34*) for data on public expenditures on inpatient and outpatient hospital usage, and for physician usage, for treatments directly involving all the effects considered in this article, including, of course, diabetes.

These economic costs pertain only to publicly (OHIP) funded medical expenditures directly attributable to diabetes and some involving diabetes with certain complications. Unlike in the ADA report cited above, the OHIP does not publish an accounting of excess prevalence of chronic complications of diabetes, of the excess prevalence of general medical conditions among people with diabetes, of the numerous possible medical expenditures paid for privately, or of the productivity losses due to disability and early mortality.

According to the data provided by the Ontario Ministry of Health, total inpatient and outpatient hospital costs incurred by OHIP in Ontario for diabetes averaged about $54.4 million (CDN dollars) annually over the 1996–1998 period. The same source indicates that OHIP expenditures for doctors diagnosing diabetes, including complications, totaled about $55.3 million for the 1998/1999 reporting year (*34*).

## Parkinson's Disease

***General results.*** Parkinson's disease (PD) is a chronic, progressive neurologic disorder affecting about 400,000 to 600,000 people, predominantly 45 years of age or older, in the United States. Reported prevalence is estimated between 200 and 300 per 100,000 population, and incidence rates vary from 5 to 24 per 100,000 per year, although studies have found that many people with PD go undiagnosed (*35,36*). The prevalence of PD in the United States is projected to increase to about 1.3 million (middle estimate) by the year 2040, as the susceptible age cohorts grow but assuming no change in current rates (*37*).

However, death rates from PD are increasing, so this prevalence rate projection may be an underestimate (*37*). It has been noted in the literature that a possible interaction between aging and exposure to neurotoxic agents is of critical concern (*38,39*). The potential exists for agents to induce delayed neurotoxicity years after cessation of exposure or as a result of low-level exposure over the life span. As the large cohort of baby boomers ages, any added increase in dysfunction as a consequence of exposure to neurotoxic agents will place additional burdens on the health-care system.

Several scientific papers reported on cost-of-illness studies; however, only one pertained to the United States, and none was located for Canada (*35,40,41*). Other papers described the social costs (*42*) and the health burdens (*36*) of PD. Another described projected neurodegenerative mortality, including deaths from PD, in the United States from 1990 to 2040 (*37*). All these studies underlined the serious and important health, social, and economic burdens of PD. As a chronic, disabling disease, PD is likely to induce significant direct medical costs, as well as considerable indirect costs. Despite pharmacologic and surgical intervention, the disease leads to severe disability, and mortality. Disability can result in devastating, personal economic consequences. Up to 15% of patients are unable to work after 5 years, and up to 80% after 9 years of illness. Special equipment needs and housing adaptations lead to even more costs on already financially stressed families.

In addition to the direct and indirect financial and economic costs, a substantial personal burden must be borne by the affected individuals and their families. This takes the form of a severe impairment to the quality of life and to personal and social function, with accompanying embarrassment and numerous other consequences, due to the adverse physical and psychiatric effects of the disease, including possible declines in mental health.

Overall, the social effect of PD can be described as premature aging of the individuals affected, impinging much more heavily on the younger PD patients. This is a reminder of the point about the potential for neurotoxic agents to accelerate the aging process and the decline in the functional capacity of the brain, and the potential for long-latency, delayed neurotoxicity raised above (*38,39*). Few articles in the literature address these personal and family consequences.

***Economic costs—case study.*** *Ontario.* According to information provided by the Ontario Ministry of Health, total inpatient and outpatient hospital costs incurred by OHIP in Ontario for PD averaged about $14.2 million (CDN dollars) annually between 1996 and 1998. The represents an average cost per case of almost $16,400 (*34*). The same source indicates that OHIP expenditures for doctors totaled almost $3.5

million for the 1998/1999 reporting year (*34*). No information was available for drug-related expenses or for any of the many other financial, economic, and social costs attributable to PD for Ontario.

*United States and other countries.* One U.S. study used the 1987 National Medical Expenditure Survey as a source of population-based information about health resource use, medical expenditure, and health status (*35*). Forty-three patients with PD were identified, and each was matched with 3 individuals without PD to estimate the costs attributable to PD. The control individuals were patients who had other chronic medical conditions but who did not have PD.

These data show the serious health and economic burdens of PD. People with PD had decreased health status, increased health expenditures, and lost productivity relative to controls. However, the article noted that because of small sample size, which inadequately represented people in the earliest and in the most advanced stages of PD and showed considerable variability in the case–control groups, these estimates of the economic burden must be used with caution.

Patients with PD accounted for significantly greater mean total expenditure than controls for the year of the study (1987). Updating those costs to 1999 U.S. dollars brings the mean expenditure for PD patients to $22,914 (median $6,436; range $640 to $226,171) and the mean for the control group to $10,458 (no other data provided for controls). The higher expenditure was mainly due to higher hospital expenditures (mean for PD $15,980, range $0–$208,905; mean for control $5,180). The apparent high mean cost for the controls is related to their being patients with other chronic illnesses, with the result that healthy, illness-free individuals, who may have had near zero or very low costs, are not represented.

Also, PD patients had higher mean prescription expenditures ($882 1999 U.S. dollars higher) and higher home-health provider expenditures ($441, 1999 U.S. dollars higher) compared to those of controls. PD patients also had a higher mean length of hospital stay than the controls at 31.6 versus 11 nights, respectively. The mean for patients with PD was highly influenced by the small sample sizes and by two patients who spent 112 and 143 nights, respectively, in the hospital.

Social function items that involved visits out of the house showed significant impairment among patients with PD. Productivity measures were also significantly lower for patients with PD. None of these items were provided with an economic measure, although such measures are very important repercussions of the disease on the patients and on society at large.

In a study from France (*41*), Le Pen et al. prospectively observed a large sample of patients with PD for 6 months. This study verified the importance of falls and the strong association between health expenditures and the intensity of clinical motor fluctuations. Average 6-month costs for patients with fluctuations was $3,513 (1999 U.S. dollars) compared to $1,912 for patients without. If patients were seen by a neurologist the costs were higher, at $3,537 compared to $1,556 for those who did not see a specialist. These numbers differ from the data in Table 3 for the Le Pen study, which are based on the mean health expenditures for all 294 PD patients in the study rather than the subcategories described above.

Recent advances in drug therapy may explain the lower relative share of hospital costs in the French study compared to those in previous reports. The French study (*41*) estimated the average yearly cost of treating PD in France at $5,129, which, if extrapolated to the 80,000 PD cases estimated for France, would yield a total annual cost of $411 million to the healthcare system in general. Again, the other personal indirect costs and productivity losses were not estimated.

Another study, from Germany (*40*), retrospectively assessed the medical costs only of PD over a period of 3 months. The mean 3-month medical cost was $4,410 (1999 U.S. dollars), which, when extrapolated to an annual basis, is $17,642 (annual range was $182–$121,835). Substantial variation was identified in the cost of treatment with drugs, which depended directly on the degree of motor fluctuations presented by the patient.

This same German study cited data from the Organisation for Economic Co-operation and Development (OECD), reported in 1996, on drug expenses for several countries, including the United States, in which $342 million (1999 U.S. dollars) was reportedly spent.

For purposes of summary and comparison, selected results of the United States, German, and French population studies are presented in Table 3. All data in the table are inflated to 1999 U.S. dollars, and extrapolated to an annual basis.

Other sources of information were located on the World Wide Web, including the Parkinson's Action Network, That organization includes a number of cost estimates for PD in the United States, although there are no real, retrievable sources for the data cited. It is claimed that according to testimony before the U.S. Senate Committee on Aging, PD costs the United States an estimated $25 billion (1999 dollars) per year. These costs are reported to be spread among afflicted families, health and disability benefit providers, Supplemental Security Income (SSI), Social Security Death Index (SSDI), Medicare, and Medicaid (*44*). A number of further claims are made (all in 1999 U.S. dollars). These include the following:

- L-Dopa and related drugs run $1,000–$6,000 per year, per patient. For the estimated 400,000–600,000 PD patients in the United States, these costs range from $400 million to $3.6 billion per year.
- Ongoing care requirements include visits to neurologists, various physical therapies, and often treatment for depression. Typical early-stage annual medical cost per patient is $2,000–$7,000. The care costs in advanced cases are higher. For the PD patient numbers above, these costs range from $800 million to $4.2 billion per year.
- Treatment and hospitalization for PD-caused falls can run $40,000 or more per patient. According to W. Koller of the University of Kansas, an estimated 38% of PD sufferers do fall, and 13% fall more than once a week (*43*). In total, these costs range from $6.1 billion to $9.1 billion per year.
- According to R. Kurlan of the University of Rochester, 31% of PD sufferers who

**Table 3.** Direct and indirect medical costs per patient due to Parkinson's disease in three countries.[a]

| | Germany (*40*) | United States (*35*) | France (*41*) |
|---|---|---|---|
| Care and nursing | $4,788[b] | $2,778[c] | $1,886[d] |
| Drug therapy | $5,360[e] | $1,609 | $1,180[f] |
| Inpatient hospital care | $4,475[g] | $16,555[h] | $2,137[i] |
| Outpatient care | $135[j] | $1,259 | — |
| Other expenses | $2,914[k] | $703[l] | $262[m] |
| Total medical cost | $17,642[n] | $22,914 | $5,465 |
| Annual lost lifetime earnings | $87,460[o] | | 4.8 sick days per 6-month period |

[a]All data in U.S. dollars. [b]Based on 3-month cost of $920 (1995 U.S. dollars). [c]Includes cost of visits to physicians, other medical providers, and home health visits by physicians and other healthcare providers. [d]Based on 6-month medical and ancillary care costs of 152 euros (EUR) and 662 EUR. [e]Based on 3-month cost of $1,030 (1995 U.S. dollars). [f]Based on 6-month cost of 509 EUR. [g]Based on 3-month cost of $860 (1995 U.S. dollars). [h]Includes cost of visits to hospitals, hospital physicians, and emergency room. [i]Based on 6-month cost of 922 EUR. [j]Based on 3-month cost of $26 (1995 U.S. dollars). [k]Based on 3-month cost of $560 (1995 U.S. dollars). [l]Includes cost of nondurable and durable goods and visual-medical and dental visits. [m]Consists of medical transportation cost of 113 EUR, over a 6-month period. [n]Based on 3-month medical cost of $3,390 (1995 U.S. dollars). [o]The annual lifetime lost earnings per person in the German study is transferred from a study of Alzheimer patients that calculated annual lost lifetime earnings of approximately $50,380 (U.S. dollars) per person over all individuals diagnosed with the disease in 1991 (*40*).

are employed will have to leave their jobs within a year (*43*). Disability income subsidies can run $30,000 or more annually. In total, these costs range from $3.7 billion to $5.6 billion per year.

- As the disease progresses, substantial disability (inability to maintain balance, walk, speak, or move) requires assisted living or nursing home care, which can exceed $100,000 per patient annually. Assuming just 5% of patients become totally disabled, these costs can range from $2 billion to $3 billion per year. If the number is 10%, the costs could range from $4 billion to $6 billion per year. It is apparent that these costs can balloon substantially if the actual rate of disability is higher.
- Adding up the costs calculated above, over the 400,000–600,000 PD patients estimated for the United States amounts to $13 billion to $28.5 billion per year. That estimate may be low, depending on the actual rate of disability that becomes prevalent, as noted in the previous point.

## Neurodevelopmental Effects and Hypothyroidism

***General results.*** Recent reports have pointed out a number of issues and vital statistics related to a reported epidemic of developmental, learning, and behavioral disabilities evident among children in both Canada and the United States and the possible contribution of neurotoxic environmental contaminants to those problems, with the actions of antithyroid agents and hypothyroidism as one suggested mechanism. These issues reflect concerns and hypotheses raised in earlier reports and studies in the scientific literature (*1–6,38*).

Hypothyroidism can refer to a condition in which the thyroid hormone available in tissues is less than normal or optimal, all the way down to its near or complete absence (*44*). Hypothyroidism can develop from genetic and autoimmune disease, can be medically induced (iatrogenic) as in the treatment of hyperthyroidism and thyroid cancer, or can be due to thyroid dysfunction associated with various environmental chemical and physical agents, such as the radiation poisoning due to the Chernobyl event (*45*).

Thyroid hormones (THs) are essential for normal growth and skeletal maturation. Although THs are essential throughout life for normal functioning of the central nervous system (CNS), they are especially needed during the fetal and neonatal periods for normal neurodevelopment to occur (*46*). During these periods, the CNS needs THs for its development. THs (mainly $T_3$) are needed for several neurodevelopmental processes, and it functions by regulating important brain genes. The THs needs, effects, and functions are regulated at different places and times in the brain, and THs play essential roles in brain development and in the development and regulation of neurotransmitter systems (*47*).

It is evident that the fetus is highly vulnerable to any insult to the thyroid system; any thyroid deficiency (or excess) may produce irreversible, profound, more specific, and possibly lasting brain and CNS effects, depending on timing and degree of aberration. If THs are lacking for a long period, extensive brain damage will occur. If they are lacking for a brief time, then the effects will be selective and specific for the region of the brain that needs them at the time of deficiency. More generally, if the developing CNS is exposed to too little TH, the result will be delayed and impaired CNS development, damage, and possibly permanent deficits (*46–49*).

Maternal THs are thought to play the predominant role in fetal development. The human fetal thyroid system does not become fully functional before term, and therefore, the gestational TH gap needs to be met by the maternal supply. Maternal thyroid deficiencies can occur at different times and severities during pregnancy, and thus may contribute to different neurodevelopmental impairments. These may include clinical or subclinical maternal hypothyroidism (screened for as elevated maternal thyroid-stimulating hormone [TSH] in the second trimester) or, as recently argued (*50*), first trimester hypothyroxinemia (low-circulating maternal $T_4$, whether or not TSH is increased) that may be more frequent and not screened for.

For present purposes, it is possible to distinguish among several manifestations of the condition: as congenital hypothyroidism (CH), as effects on the fetus other than CH, and as acquired hypothyroidism in children or adults. The thyroid gland is not essential to life, but if it is defective or absent, as in children with untreated CH, severe damage can occur, including mental retardation and possibly dwarfism (*44*). Even when screened and treated, CH children can show reduced IQs and other problems such as deficits in attention, language, and memory skills (*48,49*).

Children with CH who are inadequately treated have lower scores on intellectual, achievement, and memory tests (*46,48, 49,51*). Moreover, even CH children who were treated adequately and early performed significantly below expectation with respect to intellectual functioning compared to controls and showed significant declines in IQ with age, significantly poorer performance in visuospatial, language, and fine motor areas, and selective attention and memory deficits (*49*).

Although delays in reading comprehension and arithmetic skills evident at grade 3 were caught up by grade 6, their teachers reported that CH children were not performing as well as controls in the classroom and demonstrated difficulty with more complex subjects such as science and social studies (*48,49*). The problem stems from the delay before treatment takes effect, and the inability of the maternal TH supply to fully compensate for the fetal deficiency, which results in effects *in utero* and late gestation.

Historically, mothers who were severely hypothyroid gave birth to children who were likewise hypothyroid from birth and were born dwarfed, severely retarded, and with various deformities, and were called cretins (*44*). Mothers who experience preterm birth have children who lost the maternal TH supply before their own fetal thyroid was competent to fully supply their needs. These children, too, suffer deficits, although milder ones, depending on the extent of prematurity. Also, premature infants sometimes have a transient decrease in levels of THs following birth (hypothyroxinemia); this has been associated with a 5-fold increase in cerebral palsy at 2 years of age and an average decrease of 10 IQ points compared with that in premature infants who have normal thyroid levels (*46*).

More recently, it has been reported that pregnant women with undiagnosed hypothyroidism gave birth to children with quantifiable deficits in various neurologic measures including IQ and measures of attention (*8,51–53*). In other reports, subtle problems of cognition, attention, and behavior are overrepresented in the offspring of mothers who were hypothyroid during pregnancy (*46,51*).

Children, adolescents, and adults with acquired hypothyroidism (AH) have poor resistance to temperature, mental and physical slowing, slow metabolism, husky and slow voice, slow mentation, poor memory, and sometimes severe mental symptoms, especially depression (*44*). Adverse behavioral reactions may occur, and learning problems may persist, in juveniles treated for AH (*54*). Least favorable outcomes occur in those with more severe AH at diagnosis, and more favorable outcomes are seen in cases where euthyroidism is achieved more slowly. Critical issues in treatment include possible abnormal responses and resistance to TH. In the elderly, AH may advance aging and create additional memory problems.

***Economic and societal costs—general.*** No studies were found for this review that were designed to estimate the economic, financial, or social costs of neurodevelopmental effects and hypothyroidism. However, we did find reports of widespread developmental brain disorders that exist clinically and that are possibly associated with hypothyroidism, which is endemic. These effects have very important public health implications and whatever the cause, very substantial and numerous but undocumented costs to health care, education, public assistance, and effects on society at large.

The following statistics on public health in the United States, which involve societal costs, were reported in a study by the Greater Boston Physicians for Social Responsibility titled "In Harm's Way: Toxic Threats to Child Development" (*8*).

- It is estimated that nearly 12 million children (17%) in the United States under 18 years of age suffer from one or more learning, developmental, or behavioral disabilities. Other reports put the total at 20 million or more (*55*).
- According to conservative estimates, ADHD affects 3–6% of all school children, although recent evidence suggests the prevalence may be as high as 17%. The number of children taking the drug Ritalin for this disorder has roughly doubled every 4–7 years since 1971 to reach its current estimate of about 1.5 million. The real total may be 8 million.
- Learning disabilities alone may affect approximately 5–10% of children in public schools.
- The number of children enrolled in special education programs and classified with learning disabilities increased 191% from 1977 to 1994.
- Approximately 1% of all children are mentally retarded.
- The incidence of autism may be as high as 2 per 1000 children. One study of the prevelance of autism between 1966 and 1997 showed a doubling of rates over that time span. Within the State of California, the number of children entered into the autism registry increased 210% between 1987 and 1998 (compared to a 60% rise in population). Other studies report worldwide increases of 3.8% per year and total prevalence estimates as high as 400,000 in the United States (*55*).
- Children with these disorders are at substantial risk for school and workplace failure, drug abuse, delinquency, crime, violence and mental illness.

With respect to Canada, a recent publication of the Canadian Institute of Child Health titled "The Health of Canada's Children: ACICH Profile," reported some similar findings (*9*). These findings include the following:

- Specific data regarding the documented prevalence of neurobehavioral effects, such as ADHD and learning disabilities were presented as a question mark in the report; however, it was stated that these conditions ". . . affect a large proportion of children."
- It was reported that approximately 10–12% of all children have some degree of cognitive deficits and learning disabilities. One child in 10 received some form of remedial education during 1995 and 1996. Of these children, 51% had learning disabilities.
- According to a 1994–1995 survey of parents, there was a high prevalence of hyperactivity symptoms among children 8–11 years of age, with male children more likely to have such symptoms than females. The reported prevalence, of a variety of symptoms (e.g., cannot concentrate, cannot pay attention, distractible, impulsive, restless, hyperactive, fidgets), ranged from 48 to 60% for boys, and from 30 to 49% for girls.
- The same survey reported a substantial proportion of these children have behavioral problems, with a propensity to aggression, violence, and destructive acts.
- Children with hyperactivity and ADHD are commonly administered the medication Ritalin. The number of Ritalin pills dispensed in Canada more than doubled, from 26.8 million to 56.2 million, from 1994 to 1998.
- Although the majority of children from birth to 3 years of age experienced normal or advanced motor and social development relative to their peers, about 14% experienced delayed development.
- The overall state of diagnosis of disabilities in children was also labeled with a question mark.

For the Canadian context, other recent reports in the media (*56*) are based mostly on anecdotal information or information cited from the Centre for Studies of Children at Risk and from the U.S. Surgeon General's Report on Mental Health, 1999. These reports support the more detailed data on prevalence and incidence contained in the U.S. study cited above but in some instances (e.g., autism) suggest that the data may be underestimates.

These media sources report the following data:

- There are an estimated 3,000–5,000 children with autism in Ontario, and that prevalence among children is two to five cases per 10,000 individuals, 4–5 times more males than females.
- An estimated 5% of the child population has attention deficit disorder, but less than 2% is being treated by medication (usually Ritalin).
- One Ontario Health Study (*57*) found that the prevalence of ADHD was 9% in boys and 3% in girls; other estimates are that prevalence of ADHD is 3–5% of school-age children and the male to female ratio ranges from 4:1 to 9:1 (*55*).
- Aggressive behavior and propensity to violence appear to have increased over the last decade, with reported rates of 6–16% in males, and 2–9 % in females.
- Other disorders have been reported, such as depression, anxiety, and oppositional defiant disorder, some of which persist into adulthood, and a substantial number of individuals continue to suffer from them.
- According to other reported estimates, the prevalence of these disorders is much higher in recent reports, testimony, and study.

***Economic costs—case study.*** For this review we did not find any published, systematic, and comprehensive studies on the financial, economic, and social costs of neurodevelopmental disorders and potentially related hypothyroidism for either Canada or the United States. To provide some background, we tried to gather partial data on specific costs incurred by various parties, or estimates of what the costs might be, based on data, reasonable assumptions, and extrapolation. In some cases, the costs are paid by governments and in other cases by families or medical insurance providers. We found the following:

*Canada and Ontario.*

- The pharmaceutical product Synthoid, indicated for the treatment of hypothyroidism, was the most frequently dispensed medication in Canada in 1999, totaling just over 5 million prescriptions. Prescriptions for this medication grew by 14% in 1999. Another drug, Eltroxin, for hypothyroidism was 19 out of the top 20 dispensed drugs, totaling 1.8 million prescriptions. Reasons given for the increases were higher prevalence and earlier treatment to avoid progression of the disease. No estimate of the costs involved was available (*33*).
- According to the Ontario Ministry of Health, hospital treatment for hypothyroidism cost an average of $591,000 per year over the 1996–1998 period. This amounted to about $3,400 per case. In addition, in the reporting period 1998–1999, OHIP paid doctors almost $8.1 million for treating patients who had hypothyroidism (*34*).
- Ontario Ministry of Health data indicate that almost $1 million per year over the 1996–1998 period was the average cost for hospital treatment of patients with ADHD, autism, dyslexia and other assorted learning disorders. The majority of the cost was for ADHD, followed by autism and learning disorders; the cost for dyslexia was just over 1%. In addition, almost $8.4 million was the cost for the 1998–1999 reporting period for doctor treatments of these same diagnoses. ADHD accounted for almost 75%,

dyslexia less than 25%, and autism about 8% of these doctor costs (*34*).

- According to the Ontario Ministry of Education, some 188,000 students in Ontario need special education. The ministry has budgeted $1,218 million or about $6,477 per student for the year 1999–2000 (*58*). The Hamilton–Wentworth District School Board spent about $7,660 per student for the 1999–2000 school year; the board received only the lower average from the ministry, so the board had to make up the shortfall by diverting funds from other allocations (*59*).
- The issue of funding for special education to meet the needs of autistic, ADHD, and other learning-disabled children is controversial, and arguments exist that it is much underfunded or not funded at all. For example, anecdotal evidence indicates that it costs families about $17,000 (and more) per year (in 1999 CDN dollars) for an autistic child; this is not paid for by the healthcare system in Ontario. Extrapolating to the estimated 3,000–5,000 autistic children amounts to $51 million to $85 million per year as an estimated cost to the families.
- According to the Ontario Ministry of Correctional Services, adolescents with learning disabilities are disproportionately involved with the juvenile justice system. According to the U.S. National Center for State Courts and the Educational Testing Service in 1997, 50% of juvenile delinquents tested were found to have undetected learning disabilities (*60*). Assuming this percentage is similar in Ontario, and using ministry-provided data, the average annual cost for this 50% is $473,289,790 for those in closed custody. A similar 50% of open custody residents costs another $11,255,396 (*61*).
- As an estimate, if the 56.2 million Ritalin pills sold in Canada in 1998 cost 89 cents each (10 mg) for brand name product (*62*), that would amount to about $50 million (in 1999 dollars) per year.

*United States (62).*

- Using the estimate that nearly 12 million children in the United States suffer from some form of learning, developmental, or behavioral disability, and the special education funding per student budgeted by the Ontario Ministry of Education, and the Hamilton–Wentworth District School Board ($6,477 and $7,660, respectively) results in a comparable cost to the United States of between almost $78 billion and $92 billion per year (1999 CDN dollars). There are other estimates that the total population of people with developmental brain disorders in the United States is over 20 million (*55*). This number of cases would put the costs at $130 billion–$153 billion per year.
- If the estimated 1.5 million children in the United States are prescribed the Ritalin and each child takes 4 pills per day for 365 days per year, that would total 2.190 billion pills a year. If each pill costs 89 cents, as noted above, the cost would be $1.95 billion per year. Other estimates of Ritalin use may approach 8 million children, which is 5.3 times higher than our example above and at the example price, amounts to $10.3 billion. This hypothetical example costs $25 per week per child. Anecdotal estimates put drug costs at up to $50 per week. On the other hand, this example does not account for generic drug prices and may overestimate the amount of the drug taken. However, the example can be modified with more accurate information.
- Considering that the population of the United States is roughly (in round numbers) 30 times that of Ontario and assuming the same autism prevalence estimates of 3,000–5,000 in Ontario, extrapolates to about 90,000–150,000 cases in the United States. Using the same cost of $17,000 per child per year amounts to $1.53 billion–$2.55 billion CDN dollars per year [but see (*63*)].
- If the estimate that autism spectrum disorders affect 400,000 people in the United States is more realistic, the costs would be $6.8 billion per year. This estimate of total prevalence has implications for the estimate reported for Ontario. If the prevalence in the two locations is really approximately equal, using the relative size factor of 30 implies a total prevalence in Ontario of about 13,300, and a cost of $226 million per year in Ontario.
- There are also anecdotal reports of other drugs such as Prozac being dispensed to children who have the disorders considered here. No estimates of usage were available; however, one estimate (*62*), for the brand name product, 20 mg dose, was $2.40 per pill.

## Neurodevelopmental Effects and Intelligence Quotient

***General results.*** There is much concern in the literature that exposure to neurotoxic agents in the environment can produce deficits in certain measures of cognitive performance, such as IQ, as one effect that is easy to quantify compared to the many other neurobehavioral effects seen in studies (*21,38,39*). This has negative implications for the individuals involved but also less well-appreciated long-term consequences for the population and society as a whole.

It should be obvious that the quality of human capital must always be of paramount concern in any society, and in an era characterized as the Information Age, where knowledge and high technology are the currency of the day, it needs to be of central importance. Chemical or physical agents that can result in the "dumbing down" of the population are like nails in the economic coffin.

All knowledge, all technology and manufactured capital, all forms of social and productive organization, all sustainable environments and natural capital stocks, and all true economic innovation and progress—all growth and development—are tributary products of human creativity and praxis. Surely, the ultimate pollution is the chemical contamination of the brain, mind, and intelligence that form the source of our good fortune. This pollution not only affects the educational attainment, economic performance, and income of the individual, but it also has an impact on the dynamic performance of the economy as a whole through its effect on the quality of the human capital stock, and in turn, on society's potential production possibilities, the rate of technical progress, and the overall productivity.

Impaired child development has a number of negative outcomes and economic burdens. Lowered IQ, as measured by standardized tests, has a documented relationship with economic outcomes such as lifetime earnings. A number of studies (*13,17,18*) link small decrements in IQ around the mean to lower wages, and in turn, earnings; some well-established empirical relationships exist between IQ and several determinants of wages and earnings, as well as earnings directly.

More generally, although the IQ effects may be the easiest to quantify, they may not be the most serious in terms of life and career outcomes. Toxicants that put the nervous system at risk also affect executive function, for example, planning, organization, and initiating ideas; they may also induce problems with attention, for example, distractibility, impulsive behavior, inability to handle stress and disappointments, and to delay gratification. These effects would constitute to many a much more serious effect of toxicants with respect to success in school and in life, and with respect to possible antisocial behavior (*64*). This has obvious negative implications for excellence in the development of leaders such as chief executive officers, scientists, and management and administration officials and thus may impact both our economy and society (*64*).

As noted in the section above, evidence indicates that hypothyroidism in pregnancy negatively affects babies' intelligence, as measured by IQ, the normal distribution of which is shifted toward a higher percentage of the population scoring lower, compared to that of controls (*8,45,46,49*). There is also evidence that exposure to some toxic substances, at some life stage, results in lower IQ in the affected individual (*17,65*).

In general, lower population-average IQ shifts the distribution and increases the number of individuals who have low IQs (e.g., below 70 or 85) and who thus may be classified as retarded. It also decreases the number of gifted and exceptionally gifted individuals with high IQs (above 130), who may be the geniuses and prodigies of the immediate future. For example, if the average is lowered by 5 IQ points (in a normal distribution with a mean of 100, and standard deviation of 15), the number that score below 70 increases by a factor of 2, and the number that score above 130 decreases by a factor of 2.5 (*38,39*). The increase in the lower IQ proportion creates burdens on society in the form of a variety of social problems and costs (*38,39,65*). The loss of gifted people also has its own set of burdens and costs to society, which appear in many forms, including lost potential, excellence, and greatness.

Schettler et al. (*8*) provide some specific numbers for this scenario, for a population of 260 million. The 5-point IQ reduction in the population mean, from 100 to 95, increases the number of people below 70 from 6 million to 9.4 million. The same decrease reduces the number of gifted from 6 million to 2.4 million. This would qualify as a dumbing down of the population—not a happy prospect for society.

Such a populationwide effect is more than a hypothetical possibility. The whole population has been and continues to be exposed to a wide variety of environmental agents such as lead, other heavy metals; polychlorinated biphenyls; dioxins; pesticides; flame retardants; surfactants; hormones; cleansers; solvents; plasticizers; dyes; numerous industrial, food, and water additives; pharmaceuticals; radiation; and other substances, many of which have known toxic and neurotoxic properties, and endocrine-disrupting properties.

Given this universal exposure, the specific effects on individuals or the distribution of cases, would depend on susceptibility, and although exposure probably affects children more (as fetuses, children/adolescents/juveniles), adults are not immune. The effects may appear as multiaspect syndromes or as seemingly random events, and the environmental hazard(s) or causes may be quite unfindable by traditional methods because there is no unexposed group to act as controls and no systematic heterogeneity or diversity of exposure, and because the existing prevalence of suspect effects is already high, making rigorous statistical detection even more difficult (*66*). A populationwide effect such as IQ loss could become manifest without our knowing it for all these reasons, and because of time lags, multifactorial etiology, geographic scale and differences, and changing test standards—and because we are not really measuring for it.

We measure IQ in children infrequently, with spotty coverage, and almost never measure beyond young adulthood. Ultimately, over time, the cohorts most affected add up to the bulk of the population as a whole. This situation is at the root of the issue and one reason this case study was chosen. It is also a reason why efforts should be made to estimate the number of children and adults actually affected, so that the cost estimates presented here for populationwide IQ losses and shifts in the distribution of IQ can be proportioned and hypotheses tested. Note that the impacts estimated by Schwartz (*17*) and Salkever (*18*) in the context of lead exposure, which are adapted in the analysis that appears below, are based on the cohort of 6-year-old children as the number of children actually affected annually and not the entire population. Therefore these impacts are already fully proportioned as extensions of these works but subject to their limitations.

We did not find reference to any study reporting any populationwide IQ loss, although the "In Harm's Way" study (*8*), and the comparable Canadian report (*9*) surely indicate that a big problem exists with the neurodevelopmental health of children, and with adult health as well, even if the IQ implications are not measured or reported. Moreover, these studies are not the first to identify declines in human quality involving a number of aspects, including data showing lowered test scores on Standardized Aptitude Tests across the United States. This decline was attributed to environmental stresses, including toxic substances (*67*).

More generally, it is not evident that any such IQ study has ever been conducted or that such an attributable decline could be easily measured, and with statistical power. It does not seem that we are set up to do the measurement. The absence of evidence is not evidence of absence.

***Economic costs—case study.*** The methodology and estimation of the societal and economic costs of changes in IQ have been well developed in the context of reducing lead exposure (*13,18,68*). These methods have been used to evaluate the costs associated with children born to mothers who smoked during pregnancy. The results of these studies will be reported here. They also will be updated, adapted, extended, and used to account for dynamic economic impacts, for the purposes of the present project. As discussed above, however, note that because many possible neurobehavioral effects can be seen in studies, looking at IQ alone probably seriously underestimates the costs to society of these disorders.

*Impacts on earnings.* The seminal study by Schwartz (*17*) extended the 1985 U.S. Environmental Protection Agency report (*13*) on the costs and benefits of reducing lead in gasoline. The study by Schwartz provides a useful framework on the basis of a synthesis of various empirical studies on the contribution of IQ, schooling, and labor-force participation in the determination of earnings. It may be used as a prototypical analysis of a neurotoxic agent that results in a decline in IQ and that may also result in other cognitive deficits related to executive function, attention, hyperactivity, hearing, reading ability, language, visual perception, fine motor skills, school performance, and ultimately, participation in the labor force, lifetime earnings and success in life (*38,39,65*). Again, as discussed above, these latter deficits may be even more important than the IQ deficit in ultimate school performance and the likelihood of leading a "good life" (*38*).

Schwartz (*17*) reports that the decline in earnings equals the net present value of lifetime earnings times the sum of two percentage changes: the percentage decrease in earnings for people who do work, plus the percentage decrease in the probability of working at all (the participation rate). The second change results from the impact of neurodevelopment effects and IQ on schooling and, in turn, on participation. The estimates of these relationships are derived by synthesizing empirical estimates of others that are based on linear functions, and therefore can be criticized on the grounds that linearity may not be correct. However, the exploration of this issue is beyond the scope of the present report.

The earnings losses do not account for possible higher economic penalties per IQ point lost at the high end of the earnings scale than at the low end. Schwartz applies this decline to each child for the cohort turning 6 years of age each year. The cohort of 6-year-old children was chosen because the IQ studies are generally done in school-age children and infant studies will not necessarily show the same correlation with earnings (*68*).

Below, the original estimates of earnings losses, as reported in the reviewed studies, are presented. These first estimates are reported in their original units (1987 U.S. dollars) for illustrative purposes and because simply adjusting these for inflation to today will not necessarily reflect accurate changes in actual earnings over such a long period and they may be misleading. Later, these estimates will be updated to reflect changes in base-year dollar values, updated survey estimates of actual earnings, changes in expected lifetime earnings, and changes in the chosen cohort. It is these later estimates that are the most relevant for our current purposes.

Schwartz calculated a 1.763% loss in earnings per 1-point IQ decrement, for males and females combined. Applied to his 1987-dollar estimate of the present value (PV) of lifetime earnings of $301,000 yielded a loss per child, per IQ point, of $5,307. The Schwartz PV is calculated for a child of 6 years old, starting work at age 15, working to age 65, with the calculated earnings stream growing at 1% real per year as wage increases, and discounted at a real rate of 5% back to age 6. Because the size of his cohort of 6-year-old children was 3.9 million and we are considering the ultimate effects on the whole population, this yields a loss in earnings of almost $20.7 billion per year, per IQ point. The earnings loss is an annual one because each year the cohort of 6-year-old children is turned over and replaced in similar size and the loss must be calculated again for the new cohort (*68*).

For illustrative purposes of the current study, the average IQ loss chosen by the IJC SAB Working Group was 5 IQ points. This choice is plausible because it is consistent with relevant effects and deficits reported elsewhere (*38,45,46,65,67–69*). This means that the total income loss per year due to a 5-point IQ decrement, calculated using Schwartz's results, amounts to almost $104 billion per year in 1987 U.S. dollars.

In a subsequent study, Salkever (*18*), used Schwartz's basic approach with minor extensions to explicitly estimate the direct effects of IQ on educational attainment and participation. In addition, on the basis of more up-to-date data, Salkever developed new estimates for the effects of IQ on earnings, of schooling on earnings, and of schooling on participation. He also reports separate estimates for males and females.

Table 4 displays the estimated percent earnings loss per IQ point decrease, as reported in the Schwartz and Salkever studies. Salkever's estimates are generally higher with one exception, but especially so for females. In 1987 dollars, Salkever's estimates of earnings loss per IQ point is $6,303 per male, and $10,929 per female (*18*). However, these estimates are based on expected lifetime earnings calculated as combined for males and females for 1987 U.S. dollars ($301,000). Table 5 presents, for comparison, the earnings loss per IQ point from the two studies. Using Salkever's updates provides a substantial increase in the annual earnings loss per IQ point decrease, from $20.7 billion to $33.4 billion per IQ point decrease, or for the 5-point decrease in the present review, from $103.4 billion per year to $167 billion per year, all in 1987 dollars, earnings levels, and cohort size.

The next sections provide an update and addition to the analysis presented above using the most recently available data on earnings and demographics. We also include estimates for the Canadian context (Tables 6, 7).

Table 6 uses recent data on earnings in the United States, surveyed in 1998 for males and females separately, to update to 1999 dollars the various estimates of per-person earnings losses per IQ point decrease, according to the methods of Schwartz and Salkever. It provides a similar estimate in 1999 dollars for Canada, using Canadian earnings data as reported in the 1996 Census (*70*) and Salkever's earnings loss estimates. All these estimates are close approximations to a recent hypothetical example of $10,000 expected value of lifetime earnings loss per IQ point decrease used in the context of the children of mothers who smoked during pregnancy (*65*).

In this update, the average Canadian earnings, in 1999 dollars, of males and females participating in the labor force were $33,077 and $20,418, respectively (*71*). Many adults do not participate in the workforce or do not participate for all their potential working years. The largest such group consists of women who remain at home doing housework and rearing children.

As in Schwartz, we have assumed the opportunity cost of nonparticipation in the workforce to be half the value for employed workers of the same sex. In 1996, there were approximately 8 million male participants (*72*) in the labor force and approximately 3 million male nonparticipants. In the case of females, in 1996 there were approximately 6.8 million participants and 4.8 million female nonparticipants (*70*).

Also as Schwartz does, we have assumed a 1% real-wage growth in the future from the 1995 distribution of income and have updated his discount rate. We now use a real discount rate of 3.5% in our calculations of the net present value of lifetime earnings in the Canadian update. This discount rate is based on the October 2000, Government of Canada 30-year real-return bond issue (*73*). The updated U.S. estimates for 1999 use the same 3.5% real discount rate. For Canada, the expected lifetime earnings losses (1999 CDN dollars) per IQ point decrease, per person, are $14,838 for males and $14,594 for females.

As seen in Table 6, accounting for differences between male and female earnings in the United States reverses the earnings losses

**Table 4.** Percentage earnings loss per IQ point decrease from two studies.

| | Schwartz (*17*) | Salkever (*18*) Male | Salkever (*18*) Female |
|---|---|---|---|
| Direct + indirect effect on probability of participation | –0.47 | –0.215 | –0.911 |
| Direct + indirect effect on earnings | –1.29 | –1.879 | –2.720 |
| Total percentage effect | –1.763 | –2.094 | –3.631 |

**Table 5.** Earnings loss per IQ point for cohort of 6-year-old children in the United States, 1987 dollars.

| | Males | Females | Combined |
|---|---|---|---|
| Cohort population, mid-1980s[a] | 1,992,900 | 1,907,100 | 3,900,000 |
| Earnings loss, Schwartz (*17*) | $10,576,320,300 | $10,120,979,700 | $20,697,300,000 |
| Earnings loss, Salkever (*18*)[b] | $12,561,248,700 | $20,842,695,900 | $33,403,944,600 |

[a]The population figure for 6-year-old children in the United States in the mid-1980s was broken down by gender using the male and female ratios for 6-year-old children in the United States in 1990. In 1990, the ratio was 51.1% males to 48.9% females. [b]Earnings loss per IQ point was calculated by multiplying the earnings loss per IQ point by the number of persons within the cohort.

**Table 6.** Updated earnings loss per IQ point decrease, United States and Canada, in 1999 dollars.[a]

| | Schwartz[b,c] | Salkever[d,e] Male | Salkever[d,e] Female | Canadian update[f] Male | Canadian update[f] Female |
|---|---|---|---|---|---|
| IQ direct + indirect effect on probability of participation | $3,647 | $1,756 | $3,829 | $1,523 | $3,662 |
| IQ direct + indirect effect on earnings | $10,010 | $15,342 | $11,433 | $13,315 | $10,932 |
| Total effect | $13,680[g] | $17,098 | $15,262 | $14,838 | $14,594 |

[a]All data in this table are inflated using the "All Items"component of the U.S. or Canada Consumer Price Index. [b]The updated numbers are based on the combined net present value (calculated using a real discount rate of 3.5%) of earnings for U.S. males and females for 1998. [c]The earnings loss per IQ point is estimated by multiplying the predicted change in wages, according to Schwartz (*17*) by the combined net present value of expected lifetime earnings. A combined net present value of earnings for U.S. males and females, based on 1998 Bureau of Labor earnings data is $749,001. [d]The updated numbers are based on the net present value (calculated using a real discount rate of 3.5%) of earnings for U.S. males and females for 1998. [e]The earnings loss per IQ point is estimated by multiplying the predicted change in wages, according to Salkever (*18*), by the net present values (calculated using a real discount rate of 3.5%) of expected lifetime earnings for males and females. The net present values of earnings for U.S. males and females at age 6, starting work at age 15 and working to age 65, based on 1998 U.S. Bureau of Labor earnings and participation rate data, are $788,139 and $405,746, respectively. [f]The net present values of earnings for Canadian males and females have been multiplied by the percentage earnings loss per IQ point decrease according to Salkever (*18*). The net present values (calculated using a real discount rate of 3.5%) of earnings for Canadian males and females at age 6, starting work at age 15 and working to age 65 are $666,656 and $378,099, respectively. [g]The total effect under Schwartz was determined by multiplying the total percentage earnings loss (1.763%) by the combined net present value of earnings for U.S. males and females surveyed in 1998.

**Table 7.** Updated earnings loss per IQ point for cohort of 6-year-old children, United States, Canada, and Ontario.[a]

| | United States[b] | | Canada[c] | | Ontario[c] | |
|---|---|---|---|---|---|---|
| | Male[d,e] | Female[d,e] | Male[d,e] | Female[d,e] | Male[d,e] | Female[d,e] |
| Cohort population[f] | 2,054 | 1,966 | 210.355 | 200.245 | 79.025 | 75.095 |
| Earnings loss | $28,098,720[g]–$35,119,292[h] | $26,894,880[g]–$30,005,092[h] | $3,121,248 | $2,922,376 | $1,172,573 | $1,095,936 |

[a]All financial data in this table are inflated using the "All Items" component of the U.S. or Canada Consumer Price Index. [b]U.S. updated total earnings loss per IQ point is provided above in 1999 U.S. dollars. [c]Canada and Ontario total earnings loss per IQ point is provided above in 1999 Canadian dollars. [d]In thousands. [e]Total earnings loss per IQ point, under Schwartz (*17*), for combined males and females in the cohort of 6-year-old children for all of the United States is $54,993,600,000 (1999 U.S. dollars). Under Salkever (*18*), the combined total for all of the United States is $65,124,384,000 (1999 U.S. dollars). The combined total loss for all of Canada is $6,043,626,000 (1999 CDN dollars). The combined total loss for all of Ontario is $2,268,509,000 (1999 CDN dollars). [f]The upper range in U.S. earnings loss is based on the assumptions used by Salkever (*18*). [g]Cohort for the United States is based on 1998 data, whereas the cohorts for Canada and Ontario are based on 1995 earnings data, reported in the 1996 Census. [h]The lower range in U.S. earnings loss is based on the assumptions used by Schwartz (*17*).

of females compared to those of males determined by using Schwartz's estimate of combined lifetime earnings, and Salkever's percent income losses in Table 4, as was done previously and discussed above. That is, the earlier estimate had females' losses greater than those of males, which is reversed in Table 6.

Table 7 presents the total expected lifetime earnings loss per year, presented here in 1999 dollars, based on 1998 dollar U.S. earnings, and for the U.S. cohort of 6-year-old children as it was reported in the 1998 census (*74,75*). Table 7 shows that in the United States, annual loss per IQ point decrease is now estimated at approximately $55 billion (1999 dollars) according to Schwartz, and approximately $65 billion according to Salkever; for a 5-point IQ decrease, these losses are $275 billion and $326 billion, respectively, per year.

For Canada, Table 7 provides the estimates of earning losses per IQ point decrease for the entire Canadian and Ontario cohorts of 6-year-old children. The total annual loss in Canada is $6 billion and in Ontario it is approximately $2.3 billion. In terms of the 5-point IQ decrease considered in the current study, these losses are almost $30 billion and $11.5 billion per year, respectively.

*Impacts on social costs.* Weiss and coworkers (*28,65*) point to the importance of examining the extremes of distributions, such as those for IQ in a population. For present purposes, one particular set of social outcomes with economic consequences related to shifts in the mean of the IQ distribution is highly relevant. These researchers refer to a previous study that calculates the benefits of a 3% rise in IQ scores (*39,65*). This example could be looked at in the negative as the costs of not achieving a 3% rise, or the costs of a 3% decline. These social outcomes and the estimated impacts (percent increases of background) on their prevalence are presented in Table 8. For this review we were not able to identify or estimate economic costs usually associated with the above outcomes in most cases. However, sufficient data were located in some cases to provide the following preliminary estimate of associated costs:

- Burtraw (*76*) estimates the incremental direct costs of low birth weight among children from birth to age 15, for 1988 in the United States (*76*). Because low birth-weight rates do not change substantially from year to year, these costs can be seen as annual costs. In 1988 there were 271,000 low-birth-weight babies, and the incremental healthcare costs associated with those babies as infants were $15,000 each, for a total of $4 billion (1988 dollars). Updating these costs from 1988 to 1999 dollars, using the Medical Care component of the U.S. Consumer Price Index, involves an inflation factor of 1.81 (*31*), which would bring the total to $7.24 billion. If low-weight births increase by 12% for a decline of 3 IQ points, the cost of this increase would be $869 million. Other costs associated with low birth weight to age 15 totaled an additional $2.53 billion (1999 dollars), so the incremental cost would be another $304 million, for a total of $1.17 billion. These costs would generally be incurred every year.
- In Canada and in Ontario, in 1995–1996 there were 21,602 and 8,728 low-birth-weight babies, respectively (*77,78*). If the healthcare costs at infancy in Canada and Ontario are similar to the U.S. costs, this amounts to $399 million and $161 million (1988 CDN dollars), respectively. Updating these costs to 1999 dollars, using the Health Care component of the Canadian Consumer Price Index, involves a factor of 1.32 (*79*), which would bring the totals to $527 million and $213 million, respectively. If the incidences of low birth weight increase by 12%, then the respective costs for Canada and Ontario are $63.24 million and $25.56 million. Again, these costs would be incurred every year.
- In Ontario, from 31 March 1996 to 31 March 1999, an average of 1,091,400 people were on welfare per year, and the unweighted average benefit level in 1997, updated to 1999 Canadian dollars, was $12,965 (*32*), yielding a total welfare cost estimate of almost $14.15 billion per year. If welfare recipients increase by 18% because of a 3% decrease in average IQ score, this cost, for Ontario only, is more than $255 million per year.

**Table 8.** Increase in prevalence of selected social outcomes due to a decline of 3 points in average population IQ.

| Social outcome | Estimate of prevalence (%) |
|---|---|
| Poverty during first three years of life | +20 |
| Bottom decile HOME scores | +13 |
| Out-of-wedlock births | +15 |
| Low-weight births | +12 |
| Welfare recipiency | +18 |
| Children without parents | +20 |
| High school dropouts | +28 |
| Males interviewed in jail | +25 |
| Poverty rate | +25 |

HOME, home observation for measurement of the environment.

- In 1996, the U.S. prison and jail population reached a total of 1.7 million persons, and the cost was $32.916 billion (1999 U.S. dollars) per year (*80*). This was more than triple the population of 1980 (*80*). If an average IQ decrease of 3% implies a 25% increase in males interviewed in jail, the cost increases to $8.2 billion per year for male prisoners only. The prison and jail populations in the United States rose at a rate of 7% a year from 1990 to 1996, as reported, and may have continued at this rate of increase since then.
- Since data are available on the costs of young offender services in Ontario, as noted above (*61*), these data can be used as an example estimate of one small part of the whole cost. As noted above, the cost of youth offender services in Ontario in 1999–2000 was about $947 million (CDN dollars) per year. If the number of males interviewed in jail goes up by 25%, the youth component would imply costs of $237 million per year in Ontario alone.

Information and data on the other outcomes were not available; however, some of the costs would overlap, (e.g., welfare recipiency, poverty rate, out-of-wedlock children, and children without parents); other costs are related to the earnings losses, costs of special education, and costs from other cognitive disorders described above.

*Dynamic economic impacts on growth and development.* A consideration of the possible dynamic impacts of changes in average IQ and in the extremes of the distribution of IQ is essential, as it enters into fundamental questions of the basic production process, the quality of the various factors of production (e.g., land, labor, capital, other), productivity growth, and overall economic growth and development. At this time, economic science is unable to explain much of the observed growth in output in terms of growth in the conventional inputs (*81*). In fact, historically, less than half the United States increase in output, in productivity per capita, and in real wages can be accounted for by, first of all, the increase in capital itself, and then, by the increase in other factors (*81,82*).

That part of growth in output that cannot be explained is referred to as the residual. This residual was attributed to a general term noted as technical change or technical progress, which is itself composed of improvements in the quality of the various forms of conventional inputs—human labor, manufactured capital, resources and natural capital stocks, scientific and engineering advances, industrial organization, management know-how, and investments in human education and in research and development, as well as a number of other not otherwise measured sources of efficiency and technical change.

All these sources of inputs to the production process, and technical change, are somehow downstream or tributary to the primary input that comes from humans and their intellectual and physical labors. Even the primary products of the land-base, such as agriculture, forestry, fishing, and mining, are tributary to the human form of capital.

It is elementary economics that all factors of production act together, each needing the others to increase the potential output or production possibilities. Each factor has a quantity and quality aspect that together and separately fill the role of contributing to potential output and to various configurations of the production possibility frontier. It is called potential or possibility because in the real world many things happen that can increase or decrease the share of the maximum potential or possible output actually realized.

Although it is evident that manufactured capital can be substituted substantially for human and other forms of capital, this is not likely to be an unlimited process. There is an inherent complement between human capital, its quality, and the other forms of inputs, and the ultimate production of output.

It seems reasonable to conjecture, that if the quality of human capital is degraded through the introduction of cognitive and behavioral deficits such as decreased IQ and competence, learning disorders, inattention, and emotional and social reactivity, this will ultimately have a negative impact on the scale of potential output that is possible and the share of this possible output that is actually realized. In effect, this is creating a limitational factor. This will happen because all of the sources of production inputs and technical changes thus far identified are dependent in some fundamental way on the quality of the human capital and labor and creativity that form the systems that design, produce, install, operate, maintain, and improve them.

While lowering the mean IQ for an individual has, perhaps arguably, small economic changes overall except perhaps for that individual, lowering IQ for the population as a whole and changing the content of the extremes of the distribution of IQ is another matter. As noted above the universal exposure of the entire population to a large number of toxic substances makes such population effects a real possibility.

As we have seen, increasing the number of individuals who have low IQs, for example, below 70, acts as a drag on society through a wide variety of social and economic costs and impacts, including the propensity to violence touched on above. However, decreasing the number of individuals with the highest IQs undermines the source of the greatest human potential, genius, creativity, innovation, and achievement (intellectually, artistically, and in countless other ways). It truly reflects the degradation of the quality of human capital and will be the most felt impact in the economic, technological, and cultural spheres. It is this aspect, in particular, of the dumbing down of the population that cannot be dismissed as a "small change," still falling in the so-called normal range—which is a comment sometimes heard about the consequences of the loss of a few IQ points in the average individual. It is in fact, from an economic perspective, a form of negative technical change—technologic retrogression instead of progress.

Estimates of the earnings losses to individuals and cohorts due to decreases in IQ (and other disease states) have been presented above. These losses are examples of how the actual realized share of the potential or possible output is less than the maximum, or less than the production possibility frontier (PPF).

In criticism, one could argue that scaling these individual losses in IQ, which would reasonably put the affected individual at a competitive disadvantage in the workplace and result in income losses, up to the population level, is questionable. If everyone loses 5 IQ points, for example, then no one has been placed at a competitive disadvantage. This of course assumes immediately that it is only the relative IQ that matters, not the absolute level, implying there is no logical limit to how low the average IQ could go and still have no impact on individuals (or on the economy and society). Moreover, this point fails to consider that the population average IQ is a summary statistic, a measure of central tendency derived from the individual measures which in reality are distributed (in our case we have assumed normally) around the central tendencies (which are the same in a normal distribution). It confuses the population average with the individual scores, which are expected to show a variation. Therefore, if the average dropped by 5 points, individuals would be expected to have drops that vary above and below the average. For example, in a population of three, drops of 1, 5, and 9 points would yield an average drop of 5, but the individuals would be differentially affected in terms of any competitive disadvantage.

This point of criticism also fails to recognize that a lower population average IQ would be expected to have a global form of competitive disadvantage for that society, affecting all individuals more or less, regardless of their individual IQs and its ranking in terms of the population. That is, it is reasonable to expect that lowering the population IQ on average would have a negative overall economic impact internally, and also with respect to the competitive advantage compared to trading partners.

More generally, the following analysis is not so much concerned with scaling up individual losses to the population level, but with the possible impacts and losses on a macro scale due to the shifts in the entire distribution of IQ including the tails, the accompanying changes in the intellectual quality of human capital, and their potential contributions to the dynamics of production, technical progress, and economic and social well-being. How that can be estimated is not settled, but we explore it here.

The dynamics of interest here relate to changes in the determination of potential output, or outward shifts in the production possibility frontier. We would like to know how decreases in average IQ, and in the extremes of the distribution of IQ, interact in the economic process to induce an effect analogous to negative technical change or to dampen the growth in output and productivity, both real and potential, that would otherwise result. Put another way, the PPF is really being shifted inward relative to where it would be in the absence of the proposed impacts on human intellectual quality.

The unfortunate fact is that economic science cannot yet, and probably never will be able to—for a variety of data, measurement, and statistical problems—empirically measure and explain quantitatively the various contributions of all these factors, positives and negatives, to the processes of technical change, economic growth, and development (*80*). So we are left to making hypotheses and to examining the economic performance measures available and relevant to the issue at hand. The stakes are very large, as can be seen by examining the nature of the growth and development and the productivity growth in the recent past of the United States and Canada.

To illustrate the size of the economic growth and productivity growth that is the most relevant and simplest for the purposes of this review, we can examine real (adjusted for inflation) GDP and real GDP per man hour worked. In terms of real GDP, consider the following:

- In the United States between 1990 and 1998, the growth in real (1992 dollars) GDP in absolute dollars averaged $165,508 million per year. The average total real GDP over that same period was $6,670,909 million, and the 1998 real GDP was $7,551,540 million (*83*). If economic science can only explain about 50% of this growth, then the balance, or residual, that is unexplained except in terms of technical change as discussed above amounts to $82,754 million (1992 dollars) per year.

  Because the quality of human capital and labor, both intellectual and physical, contributes to the determination and realization of potential output, the changes in that quality, through changes in the average IQ (our example is 5%), associated changes in the contents of the extremes of the distribution (and other cognitive and behavioral deficits), would also contribute to changes, or the growth, in that output. If this lost, or negative technical change, contribution of the human capital to the total residual were only 10%, hypothetically, this would create a loss of about $8.3 billion (1992 dollars) a year in the realized growth portion alone.
- Similarly, if this lost or negative technical change contribution of the human capital to the total residual were 50%, the loss would be almost $41 billion a year. In terms of current dollars, the residual calculated for the same period is almost $171 billion, and the hypothetical loss at 10% is $17.1 billion per year, and at 50% is about $85 billion per year. This hypothetical example considers only a part of the average amount of the recent growth at the margin and does not consider possible impacts on the total output and over an extended time.
- For Canada, similar calculations yield an average absolute growth in real (1992 CDN dollars) GDP over the 1990–1999 period of almost $18 billion per year, and an average real GDP of $765 billion (*79*). The residual here is $9 billion per year, and the analogous loss would be $900 million at the 10% contribution and $4.5 billion at the 50% contribution. In current dollars, the average growth in absolute terms was $28 billion per year, for a residual of $14 billion, on top of an average $793 billion total GDP. This implies that in current dollars, the losses would be $1.4 billion or $7 billion per year, respectively.

Real growth in output and growth in productivity measured as real GDP per man-hour worked have been declining steadily from 1960 to the present in the United States. In Canada, the growth rates in real GDP have also been falling steadily from 1961; however, data on productivity indicate a slow increase from 1976 to 1999. The data reflect the well-known trends in these variables and the inability of economics to provide general, empirical explanations for the observed trends.

It is a reasonable hypothesis, however, that negative changes in the quality of human capital are at least partly responsible for these declines. At least one report concludes that there has been a serious and continuing manpower quality decline in the United States due to the ecologic changes and biologic stresses to which individuals born there were exposed during the several decades before the report's publication (*67*). For example, in the United States real GDP grew by 50% from 1960 to 1969, then by just 37% from 1969 to 1979, by 31% from 1979 to 1989, and finally by 25% from 1989 to 1998. The average per-year growth rates over those same periods were, 4.6, 3.2, 2.8, and 2.5%, respectively (*83*). Similarly for the productivity measure, real GDP per man-hour grew in total by 82% from 1960 to 1998. However, from 1960 to 1969 it grew at an average of 2.7% per year, from 1969 to 1979 it grew at 1.9% per year, from 1979 to 1989 it grew by 1.1% per year, and from 1989 to 1998 it grew at 1.0% per year. In Canada, the real GDP grew by 55% from 1960 to 1969, by 50% from 1970 to 1979, by 31.5% from 1980 to 1989, and by 24.8% from 1990 to 1999. Annual growth rates are likewise falling for these time periods (*79*). Productivity in Canada grew by 29% from 1976 to 1999, and by an average 0.35% per year from 1976 to 1979, by 1.1% from 1980 to 1989, and by 1.4% from 1990 to 1999.

## Discussion and Summary

This review has reported evidence for concern that environmental agents are causing clinical disease in humans, and that children are at particular risk. The authors found that methodologies exist to document and estimate the societal, economic, and personal costs associated with this environmentally related disease and have reviewed and reported on several studies that have provided such estimates. In most cases, the results presented are not new but reflect existing studies and data. In other cases, we have attempted to modify and extend the economic analysis in order to consider other aspects thought to be important. In some cases, the economic links and costs attributed to the effect or outcome are based on plausibility and hypothetical methods because the data and real methods do not exist to permit an empirical determination.

In this report we have also tried to apply these techniques and approaches in a limited way to four selected effects or outcomes, as case studies that are thought to have some environmental etiology. However, the report makes no definite attribution of any of the case-study effects to any particular environmental toxic substance, persistent toxic substance, or other pollutant or agent.

In the summary discussion below, the hypothesis-generating approach will be applied to an aggregation of the results that were put into a form of economic dollar cost. As a form of thought provocation, reasoned and hypothetical estimates of proportions of the case-study effects or outcomes due to environmental causes will be made.

Table 9 and the case-study tables in Appendix A are a compilation of all the costs that were identified or estimated for each case-study effect, and for each jurisdiction. The tables are structured to show the identification of societal or economic costs and impacts and jurisdictions for which data were found or could be estimated with relative ease. These data are very incomplete in most cases, either by type of cost or by jurisdiction.

It is beyond the scope of this review to factually determine what proportion of the grand total cost is attributable to environmental causes such as toxic substances, persistent toxic substances, and other chemical and physical agents. Most, if not all, of these diseases are multifactorial and may involve an environment–genetic interaction. However, some of these diseases appear to be of recent origin, that is, postindustrial age (e.g., Parkinson's disease), or are of epidemic proportions (e.g., diabetes and childhood developmental disorders), or have recent, large increases in prevalence. In all cases it seems very little is really agreed upon about what actually causes or triggers the disease; however, there are known associations in all cases with environmental agents. In general, a low proportion of cases is explainable by known risk factors, perhaps around 30% or less. These risk factors include genetics, diet, smoking, and occupation. However, as we learn more we find that these factors can have important environment interactions and cumulative effects, may be cofactors, and may be downstream in time in the causal process.

**Table 9.** Total cumulative costs identified.

| | |
|---|---|
| Total actual health care expenditures per year (Canada and U.S.) | $1.362 trillion |
| Cost of diabetes (Canada and U.S.) | $127.857 billion annually |
| Cost of Parkinson's disease annually (Ontario and U.S.) | $13.018 to $28.518 billion |
| Cost of hypothyroidism (Ontario) | $8.691 million annually |
| Costs associated with neurodevelopmental effects (Ontario and U.S.; plus Canada Ritalin costs) | $83.301 billion to $169.176 billion annually |
| Loss in earnings per IQ point decrement (Canada and U.S.) (1999 dollars) | $61 billion to $71 billion annually |
| Total income loss per year due to a hypothetical 5-point IQ decrement (1999 dollars) | $305 billion to $356 billion annually |
| Costs associated with impacts on social costs (Ontario and U.S.) | $19.86 billion annually |
| Cost of dynamic economic impacts on growth and development (Canada and U.S.) | |
| Decline of 10% of the residual | $18.5 billion (current dollars) annually |
| Decline of 50% of the residual | $92 billion (current dollars) annually |
| Total cumulative costs identified (Canada and Ontario) | $48.135 billion to $53.901 billion (CDN dollars) |
| Total cumulative costs identified (U.S.) | $519.409 billion to $739.518 billion (U.S. dollars) |
| Grand total of cumulative costs identified[a] (does not include total health care expenditures) | $567.545 billion[b] to $793.420 billion[c] annually |

[a]A decision was made not to convert this grand total of cumulative costs identified to a common currency, as this would be distorting and misleading for a variety of reasons. [b]Based on the lower limit of the cost of Parkinson's disease, the lower limit in the loss in earnings per 5-point IQ decrement, and the decline of 10% of the residual in the calculation of the cost of the dynamic economic impacts on growth and development. [c]Based on the upper limit of the cost of Parkinson's disease, the upper limit in the loss in earnings per 5-point IQ decrement, and the decline of 50% of the residual in the calculation of the cost of the dynamic economic impacts on growth and development.

In the absence of a specific determination of the proportion of the diseases that are explained by either environmental or other causes, one can only posit reasonable and alternative hypotheses about these proportions. A great many toxic and neurotoxic agents circulate freely in the environment. All people and potential progeny are constantly exposed to these complex mixtures, and the situation has not changed for many decades. Given this reality, it is neither reasonable nor prudent to assume that all these agents together have a zero effect on the human population.

Participants at the IJC workshop were asked if they thought there were zero effects; no one responded in the affirmative. Therefore, it would seem reasonable to posit that at least 10% of these costs are due to environmental causes. That would yield a minimum attributable cost of $57 billion to $79 billion per year.

If one were to consider the likelihood that some of these diseases have a greater than average environmental causation (e.g., Parkinson's disease, childhood developmental disorders, IQ decrements, and possibly diabetes), then a reasoned argument can be made to increase the proportion of the costs due to environmentally induced disease. A hair-splitting solution would apportion the prevalence equally, so a 50% proportion would emerge that way. This involves an attributable cost for the subject case studies of between $283 billion and $397 billion per year. The dynamic economic impacts on growth and development considered above and already based on a 10 and 50% proportion are also proportioned here again by the 10 and 50% applied to the cumulative grand total. This adds a measure of conservatism to the attributable costs proposed above.

At the current stage of research, apportionment cannot proceed much further. While some further evidence on causation and association could be brought forward, as noted, that is beyond the scope of the present work. A forum is needed for bringing this kind of debate to the floor. It may be possible for knowledgeable people to make such a preliminary determination on the basis of the weight of evidence, a move we recommend here. The effort should ultimately consider the entire burden of human disease from this perspective.

## Conclusion

The purpose of this study was to assemble societal and economic cost information for a suite of case-study effects or outcomes that evidence shows to be candidates for the term "environmental disease." We found that the economic and social costs associated with these case studies are very large, even though this report was only able to capture or estimate a proportion of the real costs for Canada and the United States. It is also reasonable to expect that some of these costs are directly attributable to chemical and physical agents in the environment, of which there are so many that it is not reasonable in this study to make specific attributions.

It would be useful to assemble knowledgeable people to weigh the evidence, and to involve transdisciplinary methods, in an effort to form a reasonable estimate of the likely environmental burden of diseases such as those considered here. In addition, more work is needed to expand the scope of the review and analysis reported here. The entire burden of human disease should be considered in terms of environmental causation as a preventable factor. Accounting for the economic and social costs can contribute to a better understanding of the real scope of the many issues raised by polluted environments.

## Appendix

The Appendix is a detailed compilation of costs identified or estimated for each case study, by jurisdiction.

**Table A1.** Total cumulative costs identified, United States.[a]

| | |
|---|---|
| Healthcare expenditures | $1.276 trillion |
| Cost of diabetes | $113.7 billion annually |
| Specific costs related to Parkinson's disease | $13 billion to $28.5 billion annually |
| Other sources of cost data on Parkinson's disease | $25 billion annually |
| Cost of hypothyroidism | — |
| Costs associated with neurodevelopmental effects | $81.479 to $167.188 billion annually |
| Loss in earnings per 1-point IQ decrement | $55 billion to $65.4 billion annually |
| Total income loss per year due to a 5-point IQ decrement | $275 billion to $326 billion annually |
| Costs associated with impacts on social costs | $19.13 billion |
| Cost of dynamic economic impacts on growth and development | |
| Decline of 10% of residual | $8.3 billion annually (real 1992 U.S. dollars)<br>$17.1 billion annually (current U.S. dollars) |
| Decline of 50% of residual | $41 billion annually (real 1992 U.S. dollars)<br>$85 billion annually (current U.S. dollars) |
| Total cumulative costs[b] | $519.409 billion[c] to $739.518 billion[d] |

[a]All data in 1999 U.S. dollars unless otherwise stated. [b]Total cumulative costs identified does not include total health care expenditures and the identified $25 billion cost of Parkinson's disease from other sources. Instead the range in total cumulative costs identified is based on the range in specific cost data related to Parkinson's disease ($13 billion to $28.5 billion). [c]Based on the lower limit of the loss in earnings per 5-point IQ decrement, the lower limit of other costs related to Parkinson's, the low limit of costs associated with neurodevelopmental effects and hypothyroidism and the decline of 10% of the residual, based on current dollars, in the calculation of the cost of dynamic economic impacts on growth and development. [d]Based on the upper limit of the loss in earnings per 5-point IQ decrement the upper limit of other costs related to Parkinson's disease, the upper limit of costs associated with neurodevelopmental effects and hypothyroidism and the decline of 50% of the residual, based on current dollars, in the calculation of the cost of dynamic economic impacts on growth and development.

**Table A2.** Cumulative costs identified, Canada.

| | |
|---|---|
| Healthcare expenditures | $86 billion (1999 CDN dollars) |
| Cost of diabetes | $14.157 billion annually (1999 CDN dollars) |
| Cost of Parkinson's disease | — |
| Other costs related to Parkinson's disease | — |
| Cost of hypothyroidism | — |
| Costs associated with neurodevelopmental effects | $50.018 million annually |
| Loss in earnings per 1-point IQ decrement | $6 billion annually (1999 CDN dollars) |
| Total income loss per year due to a 5-point IQ decrement | $30 billion annually (1999 CDN dollars) |
| Costs associated with impacts on social costs | $590.24 million annually |
| Cost of dynamic economic impacts on growth and development | |
| Decline of 10% of residual | $900 million annually (real 1992 CDN dollars)<br>$1.4 billion annually (current CDN dollars) |
| Decline of 50% of residual | $4.5 billion annually (real 1992 CDN dollars)<br>$7 billion annually (current CDN dollars) |
| Total cumulative costs identified (not including total healthcare expenditures) | $46.197 billion[a] to $51.797 billion[b] |

[a]Based on the lower limit of the loss in earnings per 5-point IQ decrement and the decline of 10% of the residual, based on current dollars, in the calculation of the cost of dynamic economic impacts on growth and development. [b]Based on the upper limit of the loss in earnings per 5-point IQ decrement and the decline of 50% of the residual, based on current dollars, in the calculation of the cost of dynamic economic impacts on growth and development.

**Table A3.** Total cumulative costs identified, Ontario (these are not included in the total cumulative costs identified for Canada).

| | |
|---|---|
| Healthcare expenditures | $30.4 billion (1999 CDN dollars) |
| Cost of diabetes | $109.7 million annually |
| Cost of Parkinson's disease | $17.7 million annually |
| Other costs related to Parkinson's disease | — |
| Cost of hypothyroidism | $8.691 million annually |
| Costs associated with neurodevelopmental effects | $1.772 billion to $1.938 billion annually |
| Loss in earnings per 1-point IQ decrement | $2.3 billion annually (1999 CDN dollars) |
| Total income loss per year due to a 5-point IQ decrement | $11.5 billion annually (1999 CDN dollars) |
| Costs associated with impacts on social costs | $730.56 million annually |
| Cost of dynamic economic impacts on growth and development | |
| Decline of 10% of residual | — |
| Decline of 50% of residual | — |
| Total cumulative costs identified (not including total healthcare expenditures) | $14.139 billion[a] to $14.305 billion annually [b] |

[a]Based on the loss in earnings per 5-point IQ decrement and the lower limit of the costs associated with neurodevelopmental effects and hypothyroidism. [b]Based on the loss in earnings per 5-point IQ decrement and the upper limit of the costs associated with neurodevelopmental effects and hypothyroidism.

**Table A4.** Total cumulative costs identified.

| | |
|---|---|
| **Healthcare expenditures** | |
| Actual national healthcare expenditures | |
| U.S. | $1.276 trillion (1999 U.S. dollars) or $4,640 per person |
| Canada | $86 billion (1999 CDN dollars) or $2,800 per person, 9.2% of GDP |
| Actual provincial healthcare expenditures (Ontario) | $30.4 billion (1999 CDN dollars) or $2,772 per person |
| **Diabetes** | |
| United States | |
| Total direct medical and indirect expenditures (including lost productivity) | $113.7 billion (1999 U.S. dollars)<br>Direct medical expenditures $51.2 billion<br>Indirect costs $63.12 billion |
| Canada | |
| Burden of diabetes medical care alone (incomplete study) | $1.18 billion (1999 CDN dollars) |
| Complete estimate may be as high as this figure (based on 10% of 1998 U.S. expenditures, modified to CDN dollars then updated to 1999 dollars) | $14.157 billion (1999 CDN dollars) |
| Ontario | |
| Inpatient and outpatient hospital costs (OHIP) | $54.4 million (CDN dollars) annually, 1996–1998 |
| Doctors' costs (OHIP) | $55.3 million (CDN dollars), 1998/1999 |
| Cost of diabetes (U.S.) | $113.7 billion (1999 U.S. dollars) annually |
| Cost of diabetes (Canada) | $14.157 billion (1999 CDN dollars) annually |
| Cost of diabetes (Ontario) | $109.7 million (CDN dollars) |
| **Parkinson's disease** | |
| Parkinson's disease (Ontario) | |
| Inpatient and outpatient hospital costs (OHIP) | $14.2 million (CDN dollars) annually (based on 1996–1998)<br>Average cost per case of almost $16,400 |
| Doctors' costs (OHIP) | $3.5 million (CDN dollars), 1998/1999 |
| Identified specific costs related to PD (U.S.) (1999 U.S. dollars) | |
| L-Dopa and related drugs | $400 million to $3.6 billion annually (based on 400,000–600,000 PD patients at a cost of $1,000–$6,000 annually, per patient) |
| Typical early-stage annual medical cost | $800 million to $4.2 billion annually (based on 400,000–600,000 PD patients at a cost of $2,000–$7,000 per patient (advanced cases run higher) |
| Treatment and hospitalization for PD-caused falls | $6.1 billion to $9.1 billion annually<br>$40,000 or more per patient<br>38% of PD sufferers fall; 13% fall more than once a week |
| Disability income | $3.7 billion to $5.6 billion annually<br>$30,000 or more annually per case of lost employment<br>31% of PD sufferers employed will lose employment within a year |
| Assisted living and nursing home care | |
| Assuming 5% of patients become disabled | $2 billion to $3 billion annually; $100,000 or greater per patient annually |
| Assuming 10% of patients become disabled | $4 billion to $6 billion annually; $100,000 or greater per patient annually |
| Other sources of cost data on PD (U.S.) (1999 U.S. dollars) | |
| Annual cost of PD (identified in testimony before the U.S. Senate Committee on Aging) | $25 billion annually |
| PD has significantly higher mean total expenditure | PD: $22,914; control: $10,458 |
| PD patients had higher mean prescription and home healthcare provider expenditures | Prescription ($882 higher)<br>Home health provider ($441 higher) |
| Parkinson's disease (France, Germany, other) (1999 U.S. dollars) | |
| Estimated annual cost of PD, France | $411 million ($5,129 average cost × 80,000 PD cases) |
| Medical cost of PD, Germany | $4,410 (3-month period) |
| Drug expenses for several countries, including the U.S. | $342 million (1996 OECD data) |
| Total identified costs related to PD (U.S.) | $13 billion to $28.5 billion (1999 U.S. dollars) annually |
| Identified cost of PD (Ontario; not available for Canada) | $17.7 million (CDN dollars) annually |
| **Hypothyroidism** | |
| Hypothyroidism (Ontario) | |
| Hospital treatment (OHIP) | $591,000 (CDN dollars) annually or $3,400 per case (based on 1996–1998 data) |
| Doctors' costs (OHIP) | $8.1 million (CDN dollars), 1998–1999 |
| Total cost of hypothyroidism (Ontario) | $8.691 million annually |

*(Continued)*

**Table A4.** Continued.

| **Costs associated with neurodevelopmental effects, with hypothyroidism as a suggested mechanism** | |
|---|---|
| ADHD, autism, dyslexia, and assorted learning disorders | |
| Hospital treatment (OHIP) | $1 million (CDN dollars) per year (based on 1996–1998) |
| Doctors' costs (OHIP) | $8.4 million (CDN dollars) 1998–1999 |
| Ritalin | $50.018 million (CDN dollars); 56.2 million pills sold in Canada in 1998 |
| Education (1999 dollars) | |
| Special education (Ontario Ministry of Education) | Budgeted $1.218 billion or $6,477 per student (1999–2000) |
| Special education (Hamilton–Wentworth District School Board) | $7,660 per student (shortfall had to be diverted from other allocation) |
| Autistic child (cost to family) | $17,000 (and more) annually (not paid by healthcare system in Ontario) |
| Autistic children (Ontario) (cost to families) | |
| Based on 3,000–5,000 autistic children | $51 million to $85 million annually |
| Based on 13,300 children | $226 million annually |
| Correctional services (1999 CDN dollars): cost of custody for young offenders (Ontario) | |
| 50% closed custody population | $473,289,790 annual cost |
| 50% open custody population | $11,255,396 annual cost |
| Total costs associated with neurodevelopmental effects | |
| Ontario | $1.772 billion to $1.938 billion annually (CDN dollars) |
| Canada—Ritalin only; excludes Ontario above | $50.018 million annually (CDN dollars) |
| Estimated costs of neurodevelopmental effects (U.S.) (1999 dollars) | |
| Special education | $78 billion to $92 billion annually (12 million children × $6,477 and $7,660, respectively)<br>$130 billion to $150 billion annually (20 million with developmental brain disorders) |
| Ritalin | $1.949 billion annually (2.190 billion pills at $0.89 each)<br>$10.388 billion annually [assumes 8 million children using Ritalin at $25 (CDN dollars)/week/child]. Note: anecdotal estimates put drugs at up to $50/week |
| Autistic children (U.S.) (cost to families) | $1.53 billion to $2.55 billion annually (90,000–150,000 cases, based on Ontario prevalence) (assumes Ontario cost per case of $17,000)<br>$6.8 billion annually (based on autism spectrum disorders affecting 400,000) |
| Total identified costs associated with neurodevelopmental effects (U.S.) (1999 U.S. dollars) | $81.479 billion to $167.188 billion annually |

| **Costs associated with neurodevelopmental effects and IQ** | |
|---|---|
| Estimated costs of neurodevelopmental effects and IQ, United States (1987 U.S. dollars) | |
| Loss in earnings per 1-point IQ decrement | $20.7 billion annually ($5,307 × 3.9 million); Schwartz (*17*)<br>$33.4 billion annually ($6,303 males and $10,929 females) [Salkever (*18*)] |
| Total income loss per year due to a hypothetical 5-point IQ decrement | $104 billion annually [Schwartz (*17*)]<br>$167 billion annually [Salkever (*18*)] |
| Estimated costs of neurodevelopmental effects and IQ, United States (1999 U.S. dollars) | |
| Loss in earnings per 1-point IQ decrement | $55 billion annually ($13,680 × 4.02 million) [Schwartz (*17*)]<br>$65.4 billion annually ($17,098 males and $15,263 females) [Salkever (*18*)] |
| Total income loss per year due to a hypothetical 5-point IQ decrement | $275 billion [Schwartz (*17*)]<br>$327 billion [Salkever (*18*)] |
| Estimated costs of neurodevelopmental effects and IQ (Canada and Ontario) (1999 CDN dollars) | |
| Loss in earnings per 1-point IQ decrement (based on Salkever coefficients) | |
| Canada | $6 billion annually (CDN dollars) |
| Ontario | $2.3 billion annually (CDN dollars) |
| Total income loss per year due to a hypothetical 5-point IQ decrement | |
| Canada | $30 billion annually (CDN dollars) |
| Ontario | $11.5 billion annually (CDN dollars) |
| Loss in earnings per 1-point IQ decrement | |
| Canada | $6 billion annually (1999 CDN dollars) |
| Ontario | $2.3 billion annually (1999 CDN dollars) |
| United States | $55 billion to $65 billion annually (1999 U.S. dollars) |
| Total income loss per year due to a hypothetical 5-point IQ decrement | |
| Canada | $30 billion annually (1999 CDN dollars) |
| Ontario | $11.5 billion annually (1999 CDN dollars) |
| United States | $275 billion to $327 billion annually (1999 U.S. dollars) |

*(Continued)*

**Table A4.** Continued.

| **Impacts on social costs** | |
|---|---|
| Low-weight births United States (1999 U.S. dollars) | |
| Costs of low-weight births among children from birth to age 15 | $7.2 billion annually |
| Additional costs associated with low-weight births to age 15 | $2.53 billion annually |
| Increase in low-weight births due to loss of 3 IQ points | $1.17 billion annually (assumes 12% increase in low-weight births) |
| Canada and Ontario (1999 CDN dollars) | |
| Cost of low-weight births among children from birth to age 15 | |
| Canada | $527 million annually (21,602 low-weight births 1995/1996) |
| Ontario | $213 million annually (8,728 low-weight births 1995/1996) |
| Increase in low-weight births due to loss of 3 IQ points | |
| Canada | $63.24 million annually (assumes 12% increase in low-weight births) |
| Ontario | $25.56 million annually |
| Welfare (Ontario) | |
| 18% increase in welfare recipients due to a 3% decrease in average IQ | $255 million annually (average unweighted benefit level in 1997 was $12,600<br>Total welfare cost estimate of $14.15 billion annually |
| Correctional services | |
| U.S. (1999 U.S. dollars): 25% increase in the number of males incarcerated due to 3% decrease in average IQ | $8.23 billion annually<br>In 1996 1.7 million persons were incarcerated at a cost of $30 billion |
| Ontario (1999 CDN dollars): 25% increase in number of young male offenders incarcerated due to 3% decrease in average IQ | $237 million annually<br>Cost of young offender services in 1999–2000 was about $947 million annually |
| Costs associated with impacts on social costs | |
| Canada | $590.24 million annually (1999 CDN dollars) |
| Ontario | $730.56 million annually (1999 CDN dollars) |
| United States | $19.13 billion annually (1999 U.S. dollars) |
| **Dynamic economic impacts on growth and development** | |
| United States | |
| Decline of 10% of the residual[a] | $8.3 billion annually (real 1992 U.S. dollars) (average growth in real GDP 1990–1998 was $165.5 billion)<br>$17.1 billion annually (current U.S. dollars) |
| Decline of 50% of the residual | $41 billion annually (real 1992 U.S. dollars)<br>$85 billion annually (current U.S. dollars) |
| Canada | |
| Decline of 10% of the residual | $900 million annually (real 1992 CDN dollars) (average growth in real GDP 1990–1999 was $18 billion)<br>$1.4 billion annually (current CDN dollars) |
| Decline of 50% of the residual | $4.5 billion annually (real 1992 CDN dollars)<br>$7 billion annually (current CDN dollars) |

[a]The part of growth in output that cannot be explained by the increase in capital, as well as other factors, is referred to as the "residual". This residual was attributed to a general term noted as "technical change" or technical progress, which is itself composed of improvements in the quality of the various forms of conventional inputs. The "residual" is based on the average real (adjusted for inflation) or current GDP, between the period 1990 to 1998 for the U.S., and between the period 1990 to 1999 for Canada. Note: GDP data for the U.S. was only available up to 1998.

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