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Canadian Meteorological and Oceanographic Society

Optimizing the Public and Private Sector Roles in the Provision of Meteorological Services

HLB Decision Economics Inc.

November 19, 2001

HLB DECISION ECONOMICS INC.

RISK ANALYSIS · INVESTMENT AND FINANCE · ECONOMICS AND POLICY

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EXECUTIVE SUMMARY

This study, commissioned by the Canadian Meteorological and Oceanographic Society of Canada, poses three questions relating to the formulation of a viable and effective private meteorological industry strategy in relation to economically optimal federal government provision of weather services:[1]

1. What is the economically optimal level of capital investment in meteorological infrastructure?

2. What are the economically optimal roles for the private and public sectors in the provision of meteorological technology, research and services? and

3. What policy options exist for optimising the public and private sector roles and investment levels in the provision of meteorological infrastructure and prediction services? What are the benefits and costs of these options?

As an economic analysis, the study does not address non-economic considerations in the formulation of both private and public policy.

The study draws on financial, budgetary and market data from Environment Canada and industry publications and reports. Some unpublished information was supplied by Environment Canada. As such, the data used here do not necessarily reflect recent changes in MSC finances and services. Environment Canada has indicated that any such differences are unlikely to change the study's overall conclusions.

The study yields five principal conclusions:

1. Just under three-quarters of the expenditures of Environment Canada's Meteorological Services of Canada ($159 million in fiscal year 2001) involve meteorological infrastructure activities and outputs that address a market failure and thus belong in the federal domain. The remaining expenditures, $66.5 million in fiscal year 2001, are for the production of value-added services that would be more efficiently provided by private firms;

2. The federal government has permitted the value of the capital stock of meteorological infrastructure to erode over the past 25 years. This erosion has contributed measurably to the nation's sluggish rate of growth in productivity and Gross Domestic Product. Although Environment Canada's proposed $280 million,[2] five-year capital investment plan would yield

[1] The findings and conclusions presented here are those of HLB Decision Economics Inc. and do not necessarily represent the views of the CMOS or of Environment Canada.

[2] . Note that the investment program on which the analysis of optimal capital spending is based a one-time submission by MSC to the Treasury Board Program Integrity 1 exercise on July 24, 1999. Out of the total $216 million in incremental capital and associated operating and maintenance dollars requested over five years, MSC has received $20 million (over five years) to address critical occupational and health safety issues. It should also be noted that the investment plan employed in the optimality analysis does not reflect the most current MSC investment planning assumptions. Use of the Program Integrity 1 plan are used here to analyze optimal capital sums required and associated benefits, incremental to the reference levels in 2000/01.

net benefits of $4.6 billion over ten years (a 69 percent rate of return), even higher levels of federal infrastructure investment are economically justified;

3. Environment Canada charges more than the optimal price (more than marginal cost) for meteorological infrastructure services, thereby preventing the maximization of the economic and social benefits of weather prediction. Treasury Board guidelines on cost recovery permit the use of the marginal cost pricing framework. On the other hand, the subsidies implied by the marginal cost pricing rule present certain economic and practical problems. Various pricing possibilities are available that serve the interests of public policy (see Box Essay);

4. MSC does not impute an allowance for normal profit and commercial risk into the prices it levies for its value-added products and services. This places private providers at a competitive disadvantage that limits their growth and inhibits innovation in the private sector supply of such products and services. Treasury Board guidelines permit the use of such imputations; and

5. If the federal government were to withdraw from the provision of products and services in which no evidence of market failure is apparent, the value of private sector output and employment in the production of meteorological services would more than double.

BOX ESSAY: *THE ECONOMICS OF PRICING PUBLIC GOODS -- AN OVERVIEW*

The term "public good" is used in two different, albeit overlapping senses in the economics literature. One has to do with "non-excludability." The other concerns "absence of rivalry in consumption." Early on in the literature, a broadcast from a radio or television tower was a commonly used example of public goods in both senses of the term. On non-excludability, the literature observed that once a station's signal is transmitted from its tower, any of its neighbours could receive it; no mechanism existed with which to provide it only to those who were willing to pay for it. Regarding absence of rivalry in consumption, the time one neighbour spent being entertained by the signal was observed to have no effect on the quality of the signal any other neighbor received.

Technology has altered this state of affairs in the last decade or so. DirecTV uses a satellite over the Gulf of Mexico to beam a signal toward Canada and the United States. The reception of that signal by one person neither increases DirecTV's costs nor reduces the quality of the signal anyone else receives. But these signals ***are*** subject to excludability. Any household can authorize someone answering a phone at DirecTV to charge its credit card and, in return, instantly receive access to a fraction of the signal that is "striking" its home. If the household pays an additional amount, it receives a bit more of the total signal. The cost of billing the household is DirecTV's total cost of serving it; if DirecTV provided the service free, serving the additional household would cost DirecTV nothing.

For a large and growing fraction of what is produced these days, the marginal cost of an extra unit of output is trivial in comparison to its average total cost. The copy of the paperback novel that sells for $3.95 at the supermarket checkout counter costs on the order of 20 cents to produce. Computer programs that cost millions of dollars to develop are distributed on compact disks that cost 25 cents or so. Knowledge collected by MSC that costs it many thousands of dollars to produce can be sent to an additional radio station or newspaper or producer of highly specialized weather reports for a tiny fraction of many thousands of dollars. Suppose that MSC were to employ a DirecTV-type technology to provide weather knowledge only to those willing to pay a price that, when added over all paying customers, would cover its costs of producing and distributing this knowledge. Such a procedure would exclude—possibly very many—customers whose benefits from this knowledge fall short of this average-cost price but who would happily pay the marginal-costs of serving them.

Micro-economics textbooks invariably point out that, when the price of a commodity exceeds the incremental or marginal cost of producing it, additional output would generate additional consumer benefits that would exceed the additional costs of producing this additional output. This being the case, the textbook prescription is, "Set price equal to marginal cost." This prescription is costly when, as in the cases presently at hand, the revenue from marginal-cost prices would fall short of total costs. Under such circumstances, price could always equal marginal cost only if someone or some entity willingly always subsidizes the resulting deficits. In textbook discussions, governments are almost always assumed to be the subsidizing entities.

BOX ESSAY: ***THE ECONOMICS OF PRICING PUBLIC GOODS -- AN OVERVIEW …* con't**

Governmental subsidies to equate price and marginal cost have at least two problems: First, subsidies require tax revenues. Taxes imposed on goods and services inevitably result in buyers paying more for them than their sellers receive. Even in markets where prices would otherwise equal marginal costs, taxes introduce the sorts of gaps between consumer value and supplier cost that subsidies designed to equate prices and marginal costs in other markets are aimed at eliminating. Conclusion: At a maximum, the subsidy required to reduce the gap between price and marginal cost in one market should yield benefits in that market no greater than the costs the necessary taxes impose in other markets.

The second problem with governmental subsidies to individual markets: Their costs are borne by taxpayers in general; their benefits go in considerable measure to those most actively involved in the subsidized markets. Almost all of us benefit from the general weather reports we read in newspapers, hear on the radio, or see in TV. Were these the only benefits that MSC provides, its optimal level of output would probably be considerably lower than it is presently. But it provides many other beneficial services. For example, frost alerts from MSC or independent entrepreneurs who use MSC data give fruit farmers time to set up sprinklers, smudge spots, or other equipment to repel frost. The primary beneficiaries from such reports are those who produce them, those who use them to reduce crop damage and, perhaps, fruit consumers. Taxpayers in general are not likely to be enthusiastic about such income transfers.

Because of such problems, subsidies designed to reduce gaps between prices and marginal costs in markets are unlikely to eliminate these gaps substantially even when they are very large. Fortunately, sophisticated pricing techniques have been developed in the economic literature that promise to reduce gaps between prices and marginal costs in many types of market. Two techniques are particularly prominent in this literature – "bundling" and "two-part tariffs." Bundling: if consumers differ in the values they attach to individual products in a related group of commodities, charging a single price for each of a group of carefully designed bundles can increase both revenues and buyer benefits from the group. Two-part tariffs: Charge an up-front fee that is independent of total purchases in a market together with a unit price per unit that is closer to marginal cost than an average-cost price. The up-front fee could, alternatively, be associated with a group successively lower per-unit fees.

1 INTRODUCTION

Commissioned by the Canadian Meteorological and Oceanographic Society of Canada, this study poses three questions relating to the formulation of a viable and effective private meteorological industry strategy in relation to federal government provision of weather services:[3]

- What is the economically optimal level of capital investment in meteorological infrastructure?
- What are the economically optimal roles for the private and public sectors in the provision of meteorological technology, research and services? and
- What policy options exist for optimising the public and private sector roles and investment levels in the provision of meteorological infrastructure and prediction services? What are the benefits and costs of these options?

An "optimal" investment plan is one that maximizes the economic and social benefits of various capital projects relative to their cost (where cost includes both one-time capital outlays on facilities and equipment and the yearly expense of maintenance and operations). Similarly, an optimal public-private mix of activities is one that yields maximum economic growth and social well-being at minimum-possible costs and consumer prices. While, in practice, economic analysis does not reveal the single-best investment plan, or the single-best public-private mix of activities, it can identify major mismatches between existing and optimal investment levels and market arrangements. Economic analysis can also identify those policies and investment levels most likely to redress such mismatches. These are the purposes of economic analysis in this study.

As an economic analysis, the study does not address non-economic considerations in the formulation of both private and public policy. Such considerations might include, for example, the government sector's wider mission and commitments in relation to the environment.

Throughout the study, HLB employs financial, budgetary and market data as available in Environment Canada and industry publications and reports. Some unpublished information was supplied by Environment Canada. As such, the data used here do not necessarily reflect recent changes in MSC finances and services. Environment Canada has indicated that any such differences are unlikely to change the study's overall conclusions.

1.1 The Context

Like roads, sewers and other foundational public infrastructure, meteorological infrastructure (satellite stations, radars, super-computers and related facilities and equipment) commands a significant commitment of economic resources. Every year the analysis and prediction of weather and environmental conditions require millions of dollars in capital investment; in salaries for scientists and

[3] The findings and conclusions presented here are those of HLB Decision Economics Inc. and do not necessarily represent the views of the CMOS or of Environment Canada.

other professionals, in research funding, and in the purchase of specialized forecasts by farmers, transportation companies, radio and television stations and the many other end-users of weather and environmental services. In the year 1999/2000, the capital stock of meteorological infrastructure was worth almost $300 million (over 95 percent of which was owned by the federal government). In the same year, governments, private meteorological firms and households spent fully $285 million on new prediction-related facilities and equipment, research and development, and forecasting products and services, or about $919.00 for every 100 Canadian residents.[4]

How much is enough? Notwithstanding the financial magnitude of the resource commitment summarized above, capital investment in weather-related infrastructure is small compared to spending on other economically foundational public infrastructure. For example, government (federal, provincial and other) expenditures in 1999/2000 on roads, airports, harbours and other transportation infrastructure totalled $4.7 billion, the federal share of which was $1.4 billion.[5] Private firms (toll road authorities, airlines and so on) invested an additional $3.2 billion. Government investment alone on transportation infrastructure exceeded total public and private spending on weather-related infrastructure more than 16-fold in 1999/2000 ($4.7 billion versus $285 million).[6]

Ensuring the right level of investment in foundational public infrastructure ranks highly in the federal government's national priorities. Economic studies prove that growth in national productivity – the key to improved living standards in Canada -- hinges foremost on the rate of capital investment. This is because higher rates of capital investment introduce better machinery, equipment and technology into the economy which in turn enables workers to produce more output and higher quality output per hour worked. Studies demonstrate that *public* capital (roads, sewers, weather stations etc.) is no less important than private sector investment (automobile plants, housing starts etc) in stimulating productivity growth. Better roads, for example, mean lower distribution costs, making Canadian firms more competitive. More accurate weather predictions reduce the need for farmers to hold "shock stocks" of seed inventories, and airlines can route aircraft around bad weather more safely and cost-effectively. Whether the current level of investment in meteorological infrastructure is optimal from an economic and social perspective is a question posed in this study.

Who should do what? Federal policy makers also recognize that the way in which public infrastructure services are delivered effects the influence they exert on national economic growth and social well-being. Meteorological infrastructure and services are supplied to the Canadian economy by both the public sector – principally the federal government, and by private firms. The roles played by government and firms in the "supply chain" of weather-related services are rooted in the history (dating back to the late 19th century) of weather forecasting as a scientific endeavour. Public and private roles also reflect the evolution and institutionalisation of weather prediction as a publicly provided service and, beginning in the 1950s, the emergence of some meteorological services as commercially viable businesses. The mix of public and private provision of weather services, like all foundational public infrastructure, has an important influence on the efficiency and quality of meteorological services

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[4] HLB from Environment Canada and Statistics Canada sources. See Section 2 for details.
[5] Transport Canada, *Transportation in Canada 2000*, Annual Report, 2000
[6] See Table 1 in Section 2.

available to industry and households. The wrong mix can inhibit innovation, cause higher than necessary prices and, ultimately, weaken the rate of growth in the national economy. Compared with the United States, where 55 percent of the value of weather-related infrastructure and related services is supplied by private firms, the private share in Canada is 21 percent. Whether this share is "too low," "too high," or "about right" is another question posed in this study.

1.2 Plan of the Report

The report is presented in six sections. Section 2 examines investment levels and market arrangements as they exist today. It then analyzes the economic and social benefits arising from existing meteorological services and market arrangements.

Section 3 explains the conditions for achieving optimal investment and market arrangements and examines the current situation in that context. Section 4 outlines alternative directions for federal policy in relation to optimizing capital investment and the mix of public and private market activities. The policy alternatives are evaluated and compared in Section 5 and Section 6 presents the study's conclusions. Technical details and bibliographic information are given in the appendices.

2 MARKET STRUCTURE TODAY

This section examines total spending in the provision of meteorological services and provides a summary analysis of the federal government's record of capital investment since 1976. The respective roles of the public and private sector are examined, followed by an analysis of the economic benefits associated with the provision of meteorological services.

2.1 Total Spending

As shown in Table 1, total spending on meteorological services in fiscal year 2000-2001 was $281-291 million (the range reflecting uncertainty in the spending levels of private firms). Fully 79 percent of the total represented federal expenditures of the Meteorological Service of Canada (MSC), a branch of Environment Canada. The balance, about $60 million (21 percent), represented the activity of private firms (measured on the basis of revenues - see Table 1).

(It should be noted that the Meteorological Service of Canada (MSC), the organizational entity responsible for delivering Environment Canada's *Weather and Environmental Products (WEP)* line of business, budgets for approximately $8 million on non-WEP related activities over and above the $225.5 million shown in Table.)

Table 1: Spending on Meteorological Services in Canada and United States (FY 2000-2001)

	Canada		United States	
	(Millions of Current Dollars)	% of GDP[1]	(Millions of Current Dollars)	% of GDP[2]
Total Private Spending	$55-65[3]	0.005%	$1,855–2,616[4]	0.012%–0.017%
Total Public Spending	$225.5[5]	0.021%	$1,787[6]	0.012%
Total Spending	$280.5 – 290.5	0.026%	$3,642–4,403	0.024%–0.029%

Notes to Table 1
All values expressed in millions of Canadian dollars, using an exchange rate of $1 Can = $0.6535 US.
1. Canadian GDP, FY 2001: $1,095,100 Million (Can$), Source: Statistics Canada, August 2001.
2. U.S. GDP, FY 2001: $15,426,434 Million (Can$), Source: U.S. Department of Commerce, Bureau of Economic Analysis, August 2001.
3. Baseline Status of the Private Meteorological Services Sector in Canada, Global Change Strategies International for the Canadian Meteorological and Oceanographic Society, July 5, 2001.
4. Estimates of annual revenues of the U.S. private meteorological sector are somewhat uncertain. They were estimated at $780–1,100 million (U.S.$) in 1995 by Spielger David B., "A History of Private Sector Meteorology", Historical Essays on Meteorology, 1919-1995, American Meteorological society, 1996.
HLB estimated the annual revenues in 2001 based on the following information: the number of weather services firms is currently estimated at 267 according to the NWS, up from 200 in 1995; and the U.S. CPI grew by 16.4% over the period 1995-2001. The estimates were computed as follows:
- Lower bound: $780 * (267/200) * (1 + 16.4%) / 0.6535 = $1,855 million
- Upper bound: $1,100 * (267/200) * (1 + 16.4%) / 0.6535 = $2,616 million

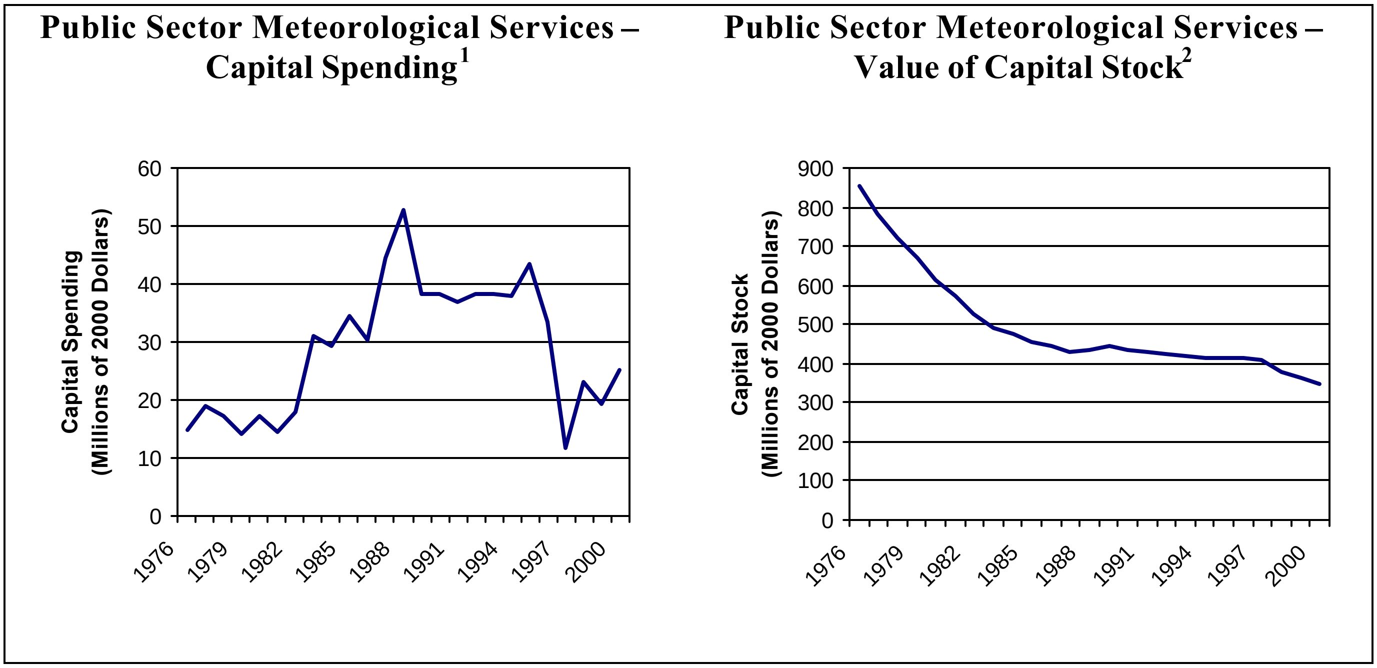
5. Planning Database, Pivot Table Version – January 5, 2001.
6. Breakdown:
- NWS: $1,087 million (Source: Budget appropriation for National Weather Service in FY 2001, "Congressional Marks Table 2001", National Weather Service, December 2000)
- Other Departments (Agriculture, Aviation, Defence, Energy and Environment): $700 million

Spending on meteorological services in the United States and Canada is proportionately about the same while the private share of total U.S. spending is proportionately greater. Total U.S. (public and private) spending of $3.6-$4.4 billion in fiscal year 2000-01 (Table 1) represented about $24–29 for each $100,000.00 of Gross Domestic Product (about $1,277–1,544 for every 100 residents). Total public and private spending that year in Canada was an estimated $26.00 for each $100,000.00 of GDP (about $919.00 for every 100 residents). An estimated 55 percent of the value of U.S. weather-related infrastructure and related services is supplied by private firms; the corresponding percentage in Canada is 21 percent.

2.2 Capital Investment

The government of Canada has allowed the value of its capital stock in meteorological infrastructure to erode over the past 25 years. Over the period 1976 to 2001, federal capital investment in meteorological infrastructure failed to keep pace with depreciation in the capital stock and price inflation (Figure 1-left panel). Since virtually all such investment is federal, Canada's stock of meteorological assets (satellite stations, radars, lightning detection equipment and so on) has declined continuously for the past quarter century. Worth an estimated $850 million in 1976, these assets are worth less than half as much today (Figure 1-Panel 2). Although declines in the value of infrastructure are not unique to the weather sector (roads, wastewater systems and other urban infrastructure have also been allowed to deteriorate relative to historic values), the weakening value of meteorological assets brings into question whether agricultural and other weather-sensitive sectors are optimally served by weather forecasting service providers.

Figure 1: Canadian Public Sector Meteorological Services - Flows and Stocks of Capital, FY 1976 – 2000 (in constant 2000 dollars)



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Notes to Figure 1

1. Public Accounts of Canada

2. Gross Capital Stock, Weather services business lines, Environment Canada. Calculated using depreciation rate of 10%[**3**], reference capital stock of $333.405M in FY 1998[from note **4** below, as provided by MSC], and annual capital expenditures [from note **5** below]. End-year, millions of constant dollars.

3. Weather and Environmental Predictions Business Line Plan 2000/2001 – 2002/2003, Environment Canada, January 26, 2000.

4. "Estimated Value of AEP Assets by Functional Usage", Environment Canada, June 21, 1998, provided by MSC. Includes WEP and air quality related assets.

5. Public Accounts of Canada, FY1976 – FY2000.

2.3 Public and Private Roles

As indicated above, the role of the private sector is significantly more prominent in the United States than in Canada. The statistics summarized in Table 1 indicate that whereas private firms account for about 21 percent of domestic market activity, the private sector represents more than half the market in the United States. As shown in Section 3, this difference reflects a policy and legislative framework in the United States under which the National Weather Service (NWS) is not permitted to provide meteorological products and services that private firms either can or do supply. Environment Canada does not restrict MSC in this way.

2.4 The Economic Value of Meteorological Services in Canada

Meteorological services create value and economic benefits in two distinct ways:

- By improving productivity in many of the nation's key industrial sectors and thereby fostering growth in the Gross Domestic Product; and

- By facilitating fewer weather-related fatalities and injuries, less time stuck in traffic jams, less destruction of wildlife and habitat, and other prediction-related improvements. Society values such benefits but does not include their value in the accounting for Gross Domestic Product.

Benefits in the first category are called "private" benefits (because they arise principally in the private sector of the economy). This study finds that each one percent increase in the net value of the meteorological capital stock leads to a 0.5 percent increase in total factor productivity and a 1.8 percent increase in the nation's GDP. The precipitous decline in the value of the meteorological capital stock over the past 25 years has thus contributed to the nation's sluggish productivity growth and the disappointing growth in living standards. HLB estimates that annual GDP would have been $15.02 billion greater had the value of the meteorological capital stock been maintained at its 1976 level.

Benefits in the second category are called "social" benefits because, despite having monetary value, that value typically is not reflected in private sector transactions. This study finds that each one-percent improvement in weather prediction accuracy yields at least $1.02 billion dollars in social benefits over a 30-year period. Since the deterioration in the capital stock has almost certainly meant foregone opportunities to improve forecasting accuracy, social benefits will have inevitably been foregone accordingly.

The following two sub-sections present the detailed analysis of private and social benefits respectively.

2.4.1 Private Benefits

As shown in Figure 2, private sector benefits of weather and environmental forecasts arise in many different industry sectors and in many different forms. Agriculture is perhaps the most obvious beneficiary. Studies show the value of frost forecasts to fruit orchard managers to be worth between $20.00 and $41.00 per hectare per day in reduced bud damage and lost yields.[7] A 1995 study assessed the value of greater crop yields associated with improved accuracy in El Nin o forecasts at $96 million (in 1990 dollars).[8]

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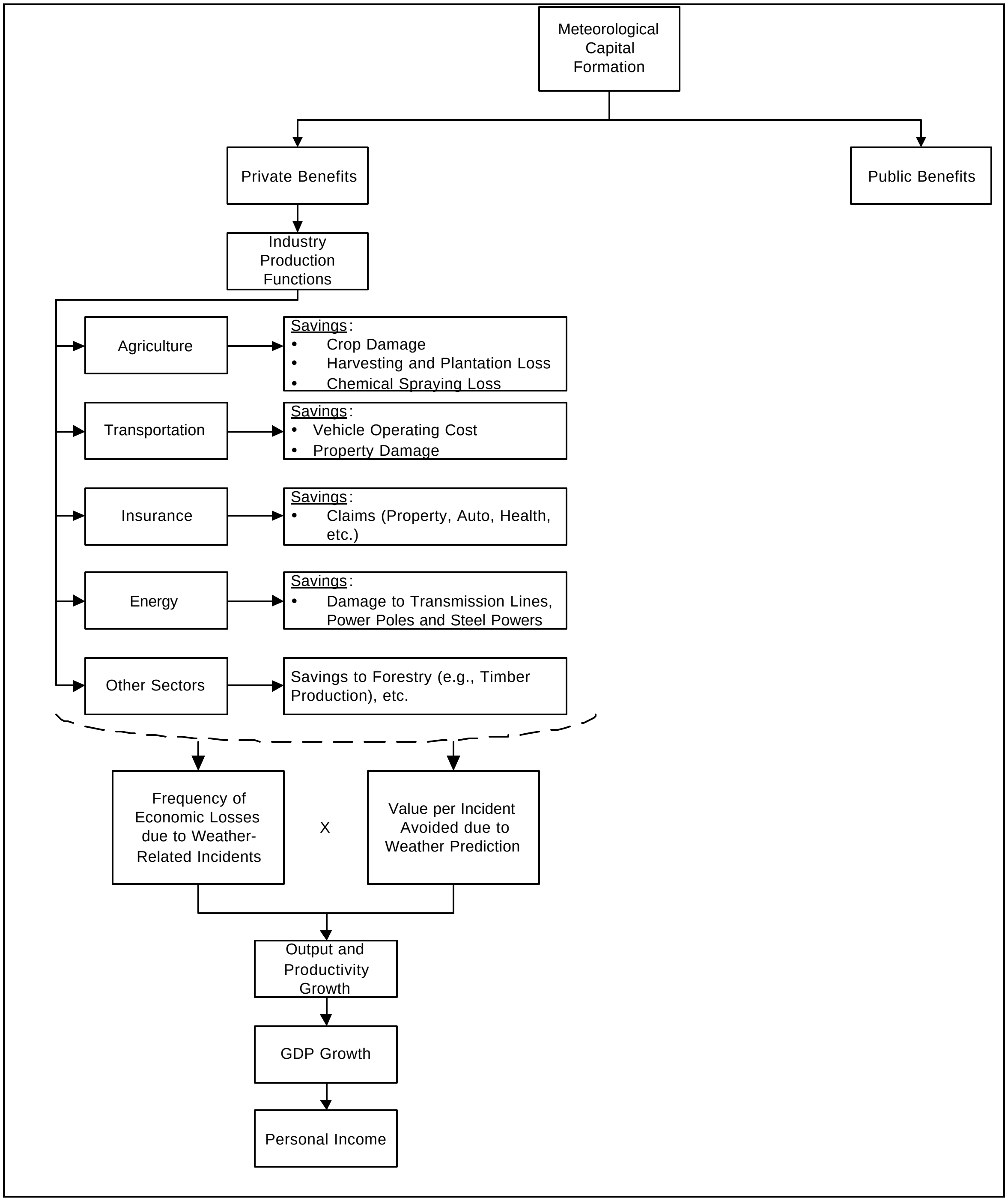
[7] From studies summarized in, Richard W. Katz and Allan H. Murphy, *Economic Value of Weather and Climate Forecasts,* Cambridge University Press, 1997 (re-valued by HLB to year-2000 Canadian dollars).

[8] R.M. Adams and others, *Value of Improved Long-Range Weather Information,* Contemporary Economic Policy, XIII, 1995

Figure 2: Private Benefits of Meteorological Services



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In the transportation sector, a recent study concluded that trucking companies value reduced schedule delays due to the anticipation of ice and other road hazards at $371.00 per hour. The adoption of just-in-time production and distribution logistics in most manufacturing sectors have led to a much-increased reliance on highly specialized weather forecasting products and services. In the lumber industry, forest products companies purchase specialized forecasts of lightning fires in order to plan harvest rotations so as to avert timber losses. As well, reduced actuarial risk in agriculture, transportation and other sectors diminishes costs in the insurance industry, with commensurate reductions in consumer premiums.

Although benefits like those described above have been quantified in a wide range of sector-specific studies, the range and diversity of effects make it difficult to roll-up the overall benefit of weather prediction throughout the economy on a sector by sector, benefit by benefit basis. Aggregate (economy-wide) modeling and measurement techniques are, however, available and viable. It is noteworthy in fact that such measurements have been applied to virtually all categories of public infrastructure (roads, water works and so on) except meteorological assets. Based upon such studies, a wide consensus emerged that public infrastructure makes a measurable and significant contribution to national productivity growth.[9]

Accordingly, HLB has employed the aggregate method to establish whether meteorological infrastructure investment gives rise to productivity growth in the national economy. We find that the effect is measurable, significant and comparable in magnitude to impact of other forms of public infrastructure.

Appendix A presents the detailed models and estimation procedure. The findings are summarized below.

Measurement Framework

Real output (GDP) may be viewed as the product of the number of workers in the economy times the production per worker. GDP growth comes from more workers, greater productivity per worker, or both.[10] The size of the workforce is determined by net immigration rates and cyclical levels of unemployment. Productivity growth comes from education, capital investment, innovation and research and development.

Historically, it has been productivity growth that has been crucial to Canadian economic growth. It is well known that the productivity of labour, in addition to relying on the quality of labour, depends on the total quantity of capital per worker. The greater the capital intensity per worker, the more leverage the worker has on production. Less obvious, but of enormous economic importance, is that productivity growth, by enabling manufacturers to offer the same or higher quality products with smaller price

[9] E. Garlic, *Infrastructure Investment: A Review Essay*, Journal of Economic Literature, September, 1994; See also, Wisner, Robert, *Infrastructure and Regional Economic Performance: Comment*, New England Economic Review, September/October 1991

[10] More precisely, growth comes from more hours worked, more output per hour worked, or both. See Appendix A. See also, David Lewis, *The Role of Public Infrastructure in the 21st Century,* Special Report 220, National Research Council, Washington D.C., 1988

increases, facilitates improved real wage rates and thus higher living standards. When in the 1990s automobile manufacturers invested in state-of-the-art robotic production lines, for example, the value of automobile output per worker increased, and economic growth increased with it. Canadian manufacturers thus became more competitive and real wage rates rose for the first time in many years.

Public infrastructure investment has been found to be productive in the same way. Studies demonstrate that improved highway capacity and pavement quality, by reducing congestion and delay, enables manufacturers to adopt highly productive just-in-time production methods, with commensurate gains in productivity. We can hypothesize, therefore, that when weather forecasts facilitate improved crop yields, reduced production delays and so on, the forecasts are actually facilitating the production of more economic output per hour, namely *productivity*.

Econometric Model

To test the hypothesis -- to measure the effect of meteorological services on productivity and output growth, Appendix A establishes "production function" equations that test, for the period 1976 to 2000, the statistical significance of the hypothesized cause-and-effect relationship between GDP growth, and (1) the size of the labour force; (2) the change in the value of the stock of private capital due to new investment; and (3) the change in the value of the stock of public capital due to new investment.

Appendix A also establishes "productivity equations" that test for the same 1976 to 2000 period, the statistical significance of the hypothesized cause-and-effect relationship between productivity growth and (again) the size of the labour force, changes in the value of the stock of private capital due to new investment, and changes in the value of the stock of public capital due to due to new investment.

In the case of the public capital stock (highways, sewers, schools, government meteorological facilities and equipment), the meteorological capital assets have been separated out in order to determine whether their effect is distinct and statistically significant. The principal findings are as follows:

Results

Based on the econometric model, we can conclude that public investment in meteorological facilities and equipment has a statistically significant effect on productivity and economic output. Specifically:

- Each ten percent change in the net value of the meteorological capital stock leads to a 0.5 percent change in productivity;
- Each ten percent change in the net value of the meteorological capital stock leads to a 1.8 percent change in the nation's Gross Domestic Product.

These findings are significant at the 99 percent level of statistical confidence. These findings are similar in magnitude to those obtained by U.S. researchers in relation to the effect of other categories of public infrastructure.[11]

[11] See M. Shaw Nadiri and Theo anis P. Ammonias, *Contributions of Highway Capital to Industry and National Productivity Growth,* Federal Highway Administration, September 1996

Shrinkage in the Capital Stock of Meteorological Capital Assets has Diluted Canada's Productivity and Economic Growth

The relationships identified above hold for both increases and decreases in the capital stock. In other words, whereas *increasing* the value of the capital stock of meteorological infrastructure leads to increased productivity and output, *decreasing* the capital stock leads to reduced productivity and output. As shown earlier in Figure 1, reduced federal investment levels led to material shrinkage in the meteorological capital stock over the period 1976 to 2000. This is turn has meant less growth in national productivity and GDP and, in consequence, diminished personal income and household living standards. In short, the slow-down in government meteorological investment has diluted Canada's productivity and economic growth.

The implications of shrinkage in the capital stock are quantified in Table 2. The table shows that, based on the models developed in Appendix A, the average annual growth rate in productivity over the period 1976 to 2000 would have been 0.22 percent greater if the value of the meteorological capital stock had been maintained at the 1976 level. Seemingly small, the compounding effects of productivity growth are such that average annual GDP would have been $15.02 billion greater than actually achieved over the 25-year period.

In short, the failure to sustain the value of the nation's meteorological assets contributed to Canada's sluggish performance in productivity growth, output growth and growth in living standards over the past two and half decades.

Table 2: The Impact of Government Investment in Meteorological Services on Private Sector Productivity and Output: A Counterfactual Analysis (1976 – 2000)

	Average Annual Change in Productivity	Average Level Productivity	Average Annual Change in Private Sector Output	Average Level of Private Sector Output (Millions of 2000 Dollars)
Under Actual Meteorological Investment Levels	-0.26%	0.417	3.03%	521,339
Had Investment Been Sufficient to Maintain the Capital Stock at the 1976 Level	-0.09%	0.425	3.25%	536,592

HLB Decision Economics from econometric equations in Appendix A.

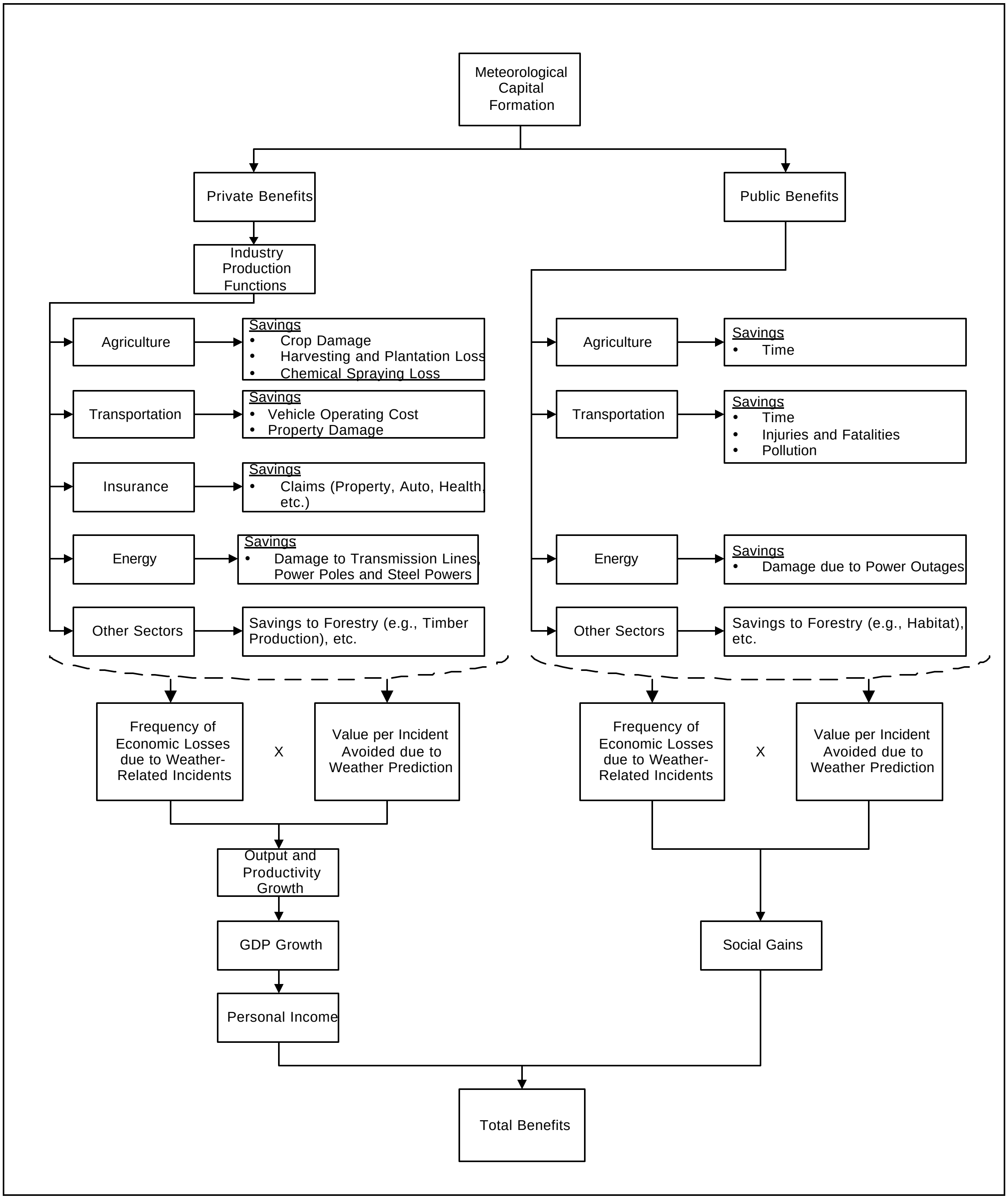
2.4.2 Social Benefits of Meteorological Services

As shown in Figure 3, the social value of weather and climate prediction arises in many sectors of the economy. Market analyses demonstrate that, as an expression of such value, firms and households are willing to pay for weather and climate predictions that reduce the risk of fatalities and injuries, the chances of being stuck in commuter traffic jams, the destruction of habitat and wildlife and so on.[12] In economic analysis, the amount people are willing to pay in order to obtain the benefits of a service is a direct measure of how much value they assign to the service. Since social values are, by definition, not accounted for in GDP, such values are additive to the economic benefits discussed in the section 2.4.1.

This study finds that each one-percent improvement in weather prediction accuracy yields at least 1.02 billion in social benefits over a 30-year period. Since the deterioration in the capital stock has almost certainly meant foregone opportunities to improve forecasting accuracy, social benefits will have inevitably been foregone accordingly.

[12] Private firms in Canada sell specialized weather forecasts and related products to industrial and household consumers worth $60 million annually. See also, Richard W. Katz, et al. al. (op. cit.)

Figure 3: Public Benefits of Meteorological Services



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Measurement Framework

Economic analysis and probability theory provide the measurement framework within which the quantitative significance of social benefits can be examined. Presented in detail in Appendix B, the framework is essentially a three factor equation, as follows:

Social Value **=**

the frequency of adverse incidents of type i, *times*

the reduction in adverse incidents of type i due to weather prediction, *times*

the economic value (based on peoples' willingness to pay) of mitigated adverse effects of incidents of type i.

The first two factors are probabilities. Consider "floods." Floods occur within an uncertain but quantifiable probability range. The frequency with which weather prediction will facilitate mitigating behaviour and the avoidance of social loss depends upon the accuracy of the forecast and the nature of loss (lives, injuries) and is also quantifiable within a probability range. Finally, the economic value of mitigated social loss is measurable from *willingness to pay* studies. Such studies employ a variety of techniques, including behavioural research, stated preference surveys, hedonic price models and market research.

Findings

Appendix B presents HLB's application of the social value equation over a range of sectors. Although we do not consider the analysis comprehensive, it does provide an indicative, if conservative, expression of the quantitative significance of social benefits. The results are summarized in Table 3 and a selected bibliography of relevant industry-level analysis is given at the end of the report. The findings reflect event probabilities over a 30-year period and unit values of life, injury and other social factors in general use by federal Departments and approved by the Treasury Board.

As reported in Table 3, the analysis indicates that each one-percent improvement in the accuracy of weather prediction yields an estimated $1.02 billion in social benefits over a 30-year period. Since the number of sectors and social benefit categories covered in Appendix B is limited, there is an estimated 75 percent probability that actual social benefits are greater than those reported Table 3.

Shrinkage in the Capital Stock of Meteorological Capital Assets has Meant Fewer Social Benefits from Improved Weather Prediction

Deterioration in the capital stock has almost certainly meant foregone opportunities to improve forecasting accuracy. As shown later in the report, the Meteorological Service of Canada (MSC) estimates that its proposed new investment plan will reduce the rate of system failures and will likely to improve short-term (next-day) forecasting accuracy by about 2.5 percent. Assuming, conservatively, that dilution in the capital stock since 1976 led to missed opportunities for improved accuracy of the same amount (2.5 percent), social benefits of an estimated $2.6 billion will have been forgone over the period ($1.02 billion per one-percent improvement in accuracy *times* a 2.5 percentage point improvement yields $2.6 billion).

Table 3: Probability Analysis of the Social Benefits of Meteorological Services in Canada

Sectors	Savings over 30 Years due to a 10% Weather Prediction Improvement (2000 Dollars)	Savings over 30 Years for Each 1% Weather Prediction Improvement (2000 Dollars)
Agriculture		
Crop Damage		
Harvesting Loss		
Plantation Loss		
Chemical Spraying Loss		
Other Losses		
Total Loss/Gain	$2,250,000,000	$225,000,000
Transportation		
Air		
Time Savings (Flight Diversion and Cancellation, Delayed Decision)	$317,550,000	$31,755,000
Reduced Injuries & Fatalities	$17,826,480	$1,782,648
Road (Car and Bus)		
Time Savings	$7,137,314,286	$713,731,429
Reduced Injuries & Fatalities	$400,671,360	$40,067,136
Rail		
Time Savings	$45,364,286	$4,536,429
Reduced Injuries & Fatalities	$2,546,640	$254,664
Marine		
Time Savings	$30,242,857	$3,024,286
Reduced Injuries & Fatalities	$1,697,760	$169,776
Other Modes		
Time Savings	$30,242,857	$3,024,286
Reduced Injuries & Fatalities	$1,697,760	$169,776
Total Loss/Gain	$7,985,154,286	$798,515,429
Energy		
Damage due to Power Outages	N/A	N/A
Other Sectors		
Forestry: Reduced Fire Intensity	$5,177,779	$517,778
GRAND TOTAL	**$10,240,332,065**	**$1,024,033,206**

HLB Decision Economics Inc. (Appendix B)

3 OPTIMAL PUBLIC AND PRIVATE ROLES IN THE PROVISION OF METEOROLOGICAL SERVICES

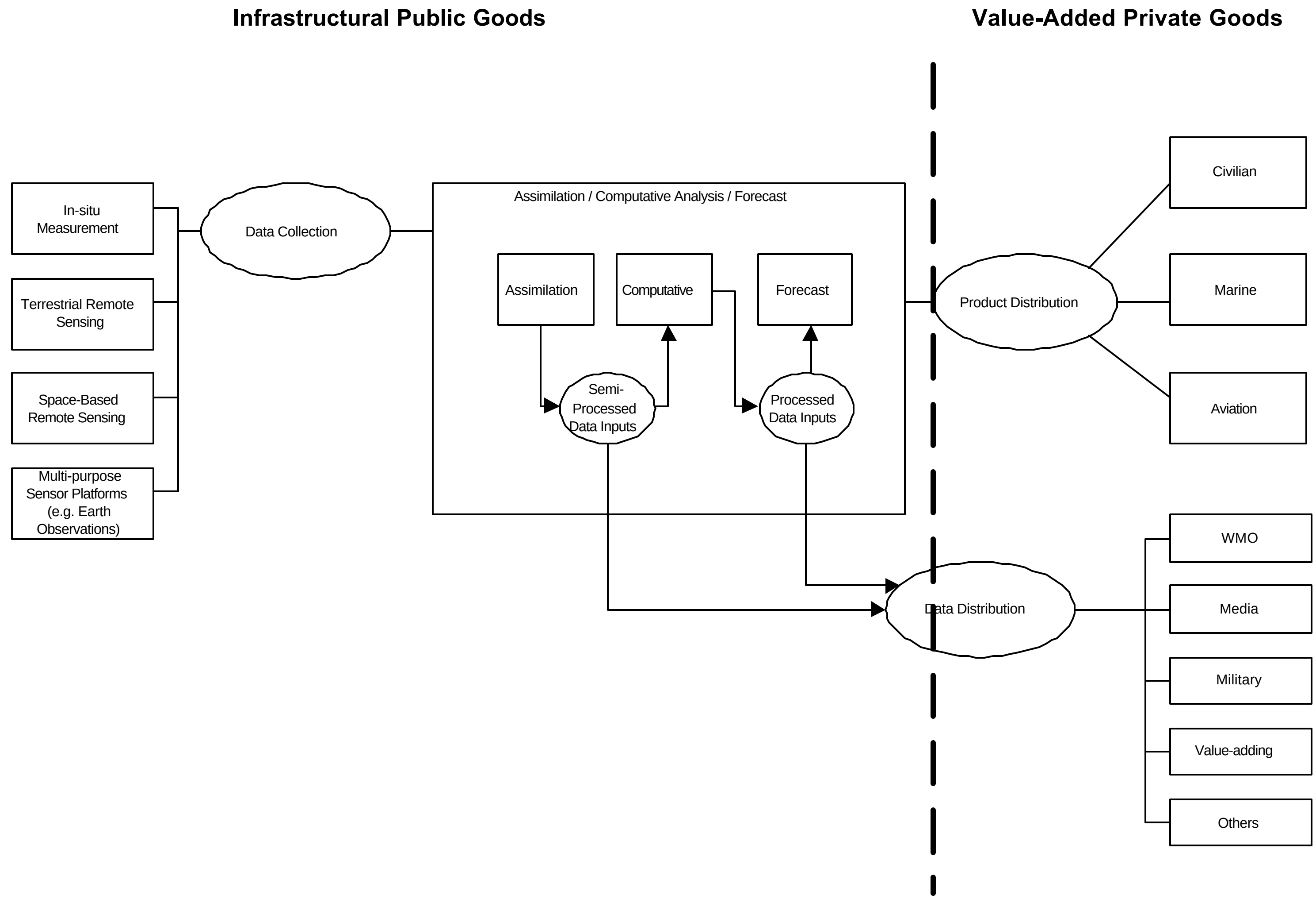
It is clear from the evidence in Section 2 that Canada has under-invested in meteorological infrastructure over the past 25 years. Before addressing the question of how much to invest going forward, however, it is necessary to tackle the broader matter of "who should do what." Should the federal government invest in meteorological infrastructure, or should such investments be left to private meteorological firms? Who should develop and sell specialized forecasting and analysis services, the government, private firms, or some combination of the two?. In short, how should the market for meteorological services be organized. Unless the market is organized appropriately, the provision of investments, the conduct of research and the delivery of specialized services will inevitably be inefficient – neither the economy nor society at-large will reap the highest-possible economic and social rewards of weather and climate analysis and prediction.

3.1 The Economics of Optimal Market Organization

As shown in Figure 4, the development of weather forecasts and other meteorological services proceeds through a supply chain that begins with major capital facilities and equipment (satellite stations, terrestrial remote sensing equipment and super computers), which in turn facilitate complex data analysis and modelling and, ultimately, the production of specialized forecasts for various end-users. The supply chain is highly capital intensive at the front-end and more labour intensive at the other. A recent popular science article describes the supply chain anecdotally, but helpfully. To paraphrase:

> *To decide whether to take an umbrella to work, people tune in to the TV or radio or check a newspaper or website. In turn, these media buy their forecasts from commercial meteorologists or the federal government. The private forecasters purchase the weather data they use to make predictions from either the federal government or from commercial data vendors who have contracts to obtain and process the raw data, radar and satellite readings from the federal government. Investment in the satellite stations, radars and other data collection equipment is financed by the federal government. In addition to supplying the basic data, the federal government also makes its own specialized forecasts.* (Jeffrey Rosenfeld, Scientific American Presents, pp28-31, April 1999).

Figure 4: Supply-Chain Architecture of Weather Forecasting



HLB Decision Economics, Inc. adapted from "Overview of Meteorological Technology Trends, Environment Canada (by Cooper Lybrand), March 1998

The question we pose here is, which of the various activities in the supply chain should be the purview of the federal government and which should be the domain of private firms? Economic theory provides the answer: The government should undertake those activities that address a market failure. Private firms should do the rest.

3.1.1 Attributes of Market Failure

"Market failure" occurs when the cost structure and technology attributes of a service are such that private firms operating in a competitive market environment cannot supply the optimal quantity, quality and price. Optimal here means the quantity, quality and price that maximize efficiency, innovation and value to the consumer. Most goods and services do not exhibit such characteristics. Accordingly, competitive supply in a free market leads in most situations to more or less the optimal outcome.

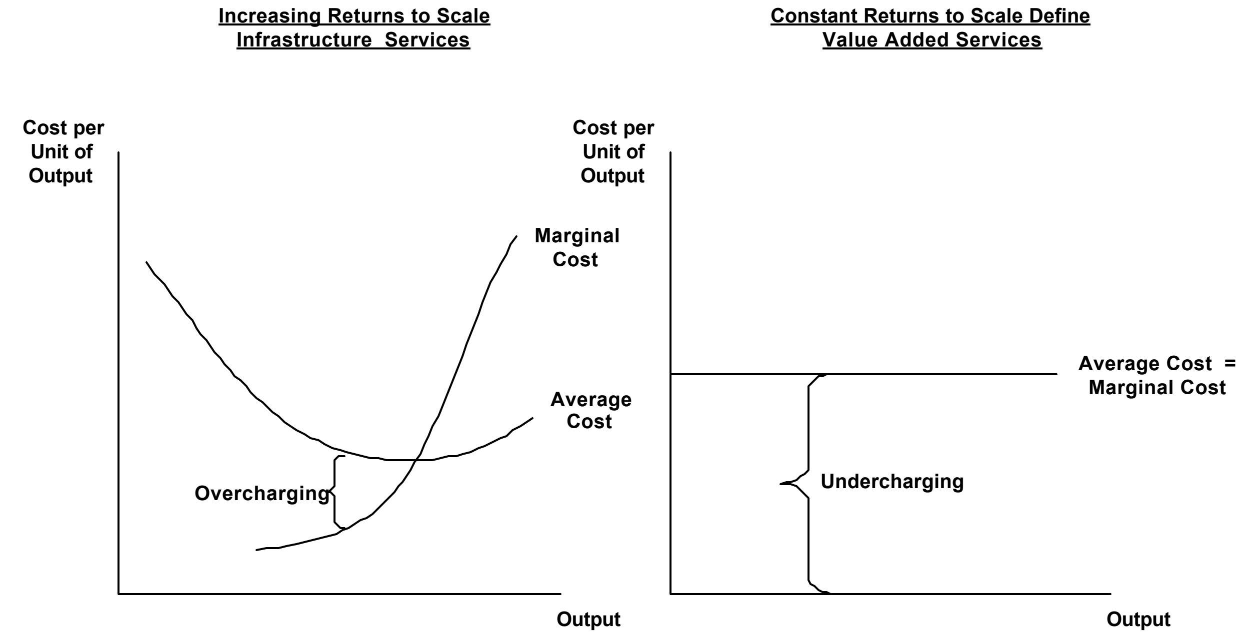
Market failure does arise, however, in the private provision of goods and services that exhibit "increasing returns to scale," also known as economies of scale. As shown in Figure 5 (first panel), the cost of such services declines sharply as the volume of output increases. An important characteristic of this class of goods and services is that the unit marginal cost of supplying them lies *beneath* their average unit cost. Since the allocation of economic resources is optimized by charging *marginal*, not average cost,[13] private firms would automatically charge too much. This is because private firms must charge average cost in order to break even and earn a normal profit. In charging too much, firms supplying such goods and services would lead consumers to reduce the quantity of service they choose to purchase to a level beneath that required for maximum economic and social benefits. Governments, on the other hand, do not need to break even in order to survive and are thus better able to optimize output levels and prices.

As shown in the left-hand panel of Figure 5, average and marginal costs are equal in the supply of goods and services that exhibit constant returns to scale (as the majority of goods and services in the economy do). This means that private, competitive provision yields optimum quantities and prices because, in setting prices at average unit cost (including normal profit), firms automatically set prices at marginal unit cost as well.

Market failure also occurs in the private provision of services that exhibit the characteristics of so-called "public goods." Public goods are defined by an attribute called "non-excludability." Non-excludability means that two or more consumers can simultaneously use the same unit of service and it is not, in general, possible to prevent certain groups or individuals from doing so. Firms seeking to maximize profits in this environment inevitably set prices too high, and produce too little service accordingly, because they fail to account for the value of "external" benefits in their pricing and production decisions.

[13] This is a fundamental and widely held tenet of market economics. For a foundational discussion, see Paul A. Samuels, *Foundations of Economic Analysis,* MIT Press, 1948

Figure 5: Definition of Optimal Public/Private Balance of Provision: Increasing and Constant Returns to Scale



Optimal Economic and Social Policy

- Single provider
- Charge users marginal cost

Type of Goods and Services

- Infrastructure services
- Pure research

Result of Single Provider

- Minimum cost of production
- Maximum benefit

Optimal Economic and Social Policy

- Many providers in competition
- Charge users marginal cost (= average cost)

Type of Goods and Services

- Value-added services
- Development research

Risk with Single Provider Involvement

- Excess cost of production
- Sub-optimal benefit

HLB Decision Economics Inc.

3.2 The Current Situation in Relation to Optimal Conditions

In light of the discussion above, the chief criterion for government involvement in the provision of meteorological goods and services is whether they address a market failure, either because they exhibit economies of scale or non-excludability (i.e., they are public goods). Meteorological goods and services that exhibit either (or both) of these characteristics are typically termed "infrastructure services" whereas all other goods and services are termed "value-added" goods and services (see Figure 5). The rule of economic optimization states that infrastructure services should be provided by the federal government and sold at prices equal to their unit marginal cost.

3.2.1 Current Division of Responsibilities Between MSC and the Private Sector

Table 4 divides the existing range of activities and outputs supplied by Meteorological Services of Canada (MSC) into those which are likely to exhibit the characteristics of infrastructure goods and services and those which are likely to display the characteristics of value-added goods and services. The assignment of outputs and activities to each category was conducted on the basis of the principles and criteria outlined above and with cost and output data supplied by MSC, Environment Canada. The analysis is presented in Appendix C and summarized in the box below.

How HLB Established the Division of Activities in Table 4

Economic criteria were used to assign WEP activities to the infrastructure category (the group of services appropriate for public provision) and the value-added category. These are:

- *The activity is likely to exhibit "increasing returns to scale." This indicates a risk of sub-optimal provision if supplied by private firms in a competitive environment;*

- *The activity is likely to exhibit the characteristics of a public good, with special reference to "excludability." "Excludability' denotes a situation in which the supply of a service cannot be restricted to those who are willing to pay. (National defense is an obvious example). Private provision is obviously not viable under such circumstances.*

HLB did not have access to the detailed data on unit costs and volumes (outputs) needed to apply the criteria on the basis of a detailed modeling and accounting framework. Indeed, the analysis needed in order to draw definitive conclusions on an activity by activity basis is extensive. Instead, we obtained, from MSC, a detailed a spreadsheet of WEP activities (see Appendix C). With the guidance of MSC staff,[14] we inspected the technological characteristics and production attributes of each activity in relation to conventional economic wisdom about the attributes of goods and services that display increasing returns or the features of public goods. Activities were assigned to the infrastructure category accordingly; all other activities were assigned to the value-added category. The overlay of non-economic criteria could, of course, shift the assignments obtained in the way described here.

The results are given in Table 4. Of the $225.5 million in MSC outlays in fiscal year 2000-01, a total of $159 million (71 percent) are found to support infrastructure activities; the balance, $66.6 million (29.5 percent) are found to support the production of value-added outputs. This means that just under three-quarters of the MSC fiscal year 2000-01 budget involved activities in which a government role is economically justified. Just under a third of MSC expenditures are in support of activities that would be

[14] HLB consulted with FMA-MSC and MSC's Special Clients and Partners Directorate. Final allocations are the responsibility of HLB alone.

supplied more efficiently by private firms. Analysis reported in Section 5 below indicates that private firms in Canada are already supplying some of the same products and services as those listed in the right-hand panel of Table 4.

3.2.2 Current MSC Pricing

We examined MSC costing and pricing policies and practices in order to determine:

- Whether infrastructure goods and services are being priced at marginal cost; and
- Whether value-added goods and services are being priced at average cost (including an imputed allowance for normal profit and commercial risk).

Although HLB was not supplied with specific cost and revenue data for the various outputs listed in Table 4, we were given access to the costing principles employed in the establishment of prices.[15]

In the case of infrastructure services, we find that the principles of "full cost allocation" in use today lead to prices that lie close to average unit cost and, accordingly, lie substantially above the unit marginal cost. In the case of value-added services, we find that prices lie close to average unit costs, but do not, by design, include an allowance for normal profit and risk.

As explained above, charging more than unit marginal cost for infrastructure services creates a sub-optimal demand for meteorological goods and services. Conversely, charging less than average unit cost for value-added services places private firms at a competitive disadvantage. Growth in the number of private firms is inhibited accordingly, as is private research, development and innovation in the provision of weather and climate forecasting products and services.

3.3 Conclusion

Five conclusions stem from the analysis in this section:

1. Just under three-quarters of the expenditures of Environment Canada's Meteorological Services of Canada ($159 million in fiscal year 2000-01) involve infrastructure activities and outputs that address a market failure.

2. The federal government has permitted the value of the capital stock of meteorological infrastructure to erode over the past 25 years. This has contributed to the nation's sluggish rate of growth in productivity, Gross Domestic Product and real personal income;

[15] Atmospheric Environment Service, Commerical Services: *Full Costing Model and Revenue Distribution Guidelines* (undated) and Environment Canada, Commercialization and Management Practices Branch, *Policy on Revenue and Collaborative Arrangements: Financial and Administrative Framework for User Charging, Collaborative Arrangements and Intellectual Property Licensing,* December 4, 2000 (unpublished)

3. MSC charges more than the optimal price for infrastructure services, thereby preventing the maximization of the economic and social benefits of weather prediction;

4. An estimated 30 percent of the expenditures of Environment Canada's Meteorological Services of Canada, $66.5 million in fiscal year 2000-01, are for the production of value-added services that would be more efficiently provided by private firms; and

5. MSC does not impute normal and risk into the prices it levies for value-added products and services. This places private providers at a competitive disadvantage that limits their growth and inhibits innovation in the private sector supply of such products and services.

Regarding conclusion 3, this study has not determined the magnitude of the difference between optimal infrastructure user fees and actual fees charged. This is because HLB did not have access to the specific cost and revenue data needed to make a service-by-service determination of optimal versus actual charges. However, in light of the significant economies of scale associated with satellite-based technology, remote sensing and other meteorological infrastructure, the policy of charging average cost will inevitably yield significant gaps between marginal cost-based prices and actual prices. On the other hand, the high level of taxpayer subsidy implied in the textbook prescription of marginal cost pricing creates economic and practical problems of its own. The Box Essay (after Table 4 below) addresses possible solutions.

Regarding conclusion 5, the difference between optimal and actual fees for MSC value-added services is quantitatively less significant than the price gap in the case of infrastructure services. Again, HLB did not have access to cost and revenue data for specific products. The costing principles in use, however, indicate that the only components missing from the optimal economic price are imputed profit and risk. While these factors are not insignificant, they are likely to create a smaller divergence between optimal and actual prices than in the case of infrastructure services.

The next Section identifies the range of policy options with which these conclusions can be addressed. Section 5 then evaluates the options and Section 6 presents the study's overall conclusions.

Table 4: Environment Canada Infrastructure and Value Added Services Expenditures[16], FY 2000-2001.

	Infrastructure Activities - Expenditures (Millions of Current Dollars)			Value Added Activities - Expenditures (Millions of Current Dollars)			Total
	Net Budgetary Expenditure	Vote Net Revenue (excl. EBP)	Gross Budgetary Expenditures	Net Budgetary Expenditure	Vote Net Revenue (excl. EBP)	Gross Budgetary Expenditures	
Research & Development	23.6	2.2	25.8	8.3	1.4	9.7	**35.5**
Production	42.8	0.0	42.8	21.4	33.6	55.0	**97.8**
Monitoring Infrastructure	47.3	22.3	69.6	0.0	0.0	0.0	**69.6**
Service Delivery	1.3	3.7	5.0	1.3	0.5	1.8	**6.8**
National Support Systems	14.7	1.1	15.8	0.0	0.0	0.0	**15.8**
Total	**129.7**	**29.3**	**159.0**	**31.0**	**35.5**	**66.5**	**225.5**

Source: Appendix C

[16] All budget figures from Planning Database, Pivot Table Version – January 5, 2001.

BOX ESSAY: *THE ECONOMICS OF PRICING PUBLIC GOODS -- AN OVERVIEW*

The term "public good" is used in two different, albeit overlapping senses in the economics literature. One has to do with "non-excludability." The other concerns "absence of rivalry in consumption." Early on in the literature, a broadcast from a radio or television tower was a commonly used example of public goods in both senses of the term. On non-excludability, the literature observed that once a station's signal is transmitted from its tower, any of its neighbours could receive it; no mechanism existed with which to provide it only to those who were willing to pay for it. Regarding absence of rivalry in consumption, the time one neighbour spent being entertained by the signal was observed to have no effect on the quality of the signal any other neighbor received.

Technology has altered this state of affairs in the last decade or so. DirecTV uses a satellite over the Gulf of Mexico to beam a signal toward Canada and the United States. The reception of that signal by one person neither increases DirecTV's costs nor reduces the quality of the signal anyone else receives. But these signals ***are*** subject to excludability. Any household can authorize someone answering a phone at DirecTV to charge its credit card and, in return, instantly receive access to a fraction of the signal that is "striking" its home. If the household pays an additional amount, it receives a bit more of the total signal. The cost of billing the household is DirecTV's total cost of serving it; if DirecTV provided the service free, serving the additional household would cost DirecTV nothing.

For a large and growing fraction of what is produced these days, the marginal cost of an extra unit of output is trivial in comparison to its average total cost. The copy of the paperback novel that sells for $3.95 at the supermarket checkout counter costs on the order of 20 cents to produce. Computer programs that cost millions of dollars to develop are distributed on compact disks that cost 25 cents or so. Knowledge collected by MSC that costs it many thousands of dollars to produce can be sent to an additional radio station or newspaper or producer of highly specialized weather reports for a tiny fraction of many thousands of dollars. Suppose that MSC were to employ a DirecTV-type technology to provide weather knowledge only to those willing to pay a price that, when added over all paying customers, would cover its costs of producing and distributing this knowledge. Such a procedure would exclude—possibly very many—customers whose benefits from this knowledge fall short of this average-cost price but who would happily pay the marginal-costs of serving them.

Micro-economics textbooks invariably point out that, when the price of a commodity exceeds the incremental or marginal cost of producing it, additional output would generate additional consumer benefits that would exceed the additional costs of producing this additional output. This being the case, the textbook prescription is, "Set price equal to marginal cost." This prescription is costly when, as in the cases presently at hand, the revenue from marginal-cost prices would fall short of total costs. Under such circumstances, price could always equal marginal cost only if someone or some entity willingly always subsidizes the resulting deficits. In textbook discussions, governments are almost always assumed to be the subsidizing entities.

BOX ESSAY: ***THE ECONOMICS OF PRICING PUBLIC GOODS -- AN OVERVIEW …*** **con't**

Governmental subsidies to equate price and marginal cost have at least two problems: First, subsidies require tax revenues. Taxes imposed on goods and services inevitably result in buyers paying more for them than their sellers receive. Even in markets where prices would otherwise equal marginal costs, taxes introduce the sorts of gaps between consumer value and supplier cost that subsidies designed to equate prices and marginal costs in other markets are aimed at eliminating. Conclusion: At a maximum, the subsidy required to reduce the gap between price and marginal cost in one market should yield benefits in that market no greater than the costs the necessary taxes impose in other markets.

The second problem with governmental subsidies to individual markets: Their costs are borne by taxpayers in general; their benefits go in considerable measure to those most actively involved in the subsidized markets. Almost all of us benefit from the general weather reports we read in newspapers, hear on the radio, or see in TV. Were these the only benefits that MSC provides, its optimal level of output would probably be considerably lower than it is presently. But it provides many other beneficial services. For example, frost alerts from MSC or independent entrepreneurs who use MSC data give fruit farmers time to set up sprinklers, smudge spots, or other equipment to repel frost. The primary beneficiaries from such reports are those who produce them, those who use them to reduce crop damage and, perhaps, fruit consumers. Taxpayers in general are not likely to be enthusiastic about such income transfers.

Because of such problems, subsidies designed to reduce gaps between prices and marginal costs in markets are unlikely to eliminate these gaps substantially even when they are very large. Fortunately, sophisticated pricing techniques have been developed in the economic literature that promise to reduce gaps between prices and marginal costs in many types of market. Two techniques are particularly prominent in this literature – "bundling" and "two-part tariffs." Bundling: if consumers differ in the values they attach to individual products in a related group of commodities, charging a single price for each of a group of carefully designed bundles can increase both revenues and buyer benefits from the group. Two-part tariffs: Charge an up-front fee that is independent of total purchases in a market together with a unit price per unit that is closer to marginal cost than an average-cost price. The up-front fee could, alternatively, be associated with a group successively lower per-unit fees.

4 ALTERNATIVE DIRECTIONS FOR FEDERAL POLICY

What policies and investment levels would maximize the net economic benefits of meteorological infrastructure investment and promote the most efficient market structure? This section identifies the options and the criteria for their assessment. The assessment itself is reported in Section 5.

4.1 Strategic Policy Options

The base case policy framework is presented next, followed by an elaboration of alternative policy directions.

4.1.1 The Base Case

The going-forward policy and investment framework is given in Environment Canada's *Weather and Environmental Predictions: Business Line Plan 2000/01-2003* dated January 26, 2000. As shown in Table 5, The Business Plan (and subsequent amendments) calls for $124.6 million in new capital investment, plus an estimated $85.6 million in associated operating and maintenance expenditures (in current dollars). Although this level of capital investment would help close the infrastructure investment gap identified earlier, we find in the next Section that more investment would be needed to maximize economic and social returns.

The Business Plan does not anticipate any structural change in the mix of infrastructure and value-added activities performed by Environment Canada.

4.1.2 Strategic Policy Options for Shifting Toward Optimal Provision of Meteorological Services

The strategic policy options available here are fundamentally three:

1. Adjust the level of MSC capital investment in meteorological infrastructure to a level that maximizes economic returns;

2. Withdraw from the provision of value-added products and services that would be more efficiently supplied by private firms; and

3. Implement pricing policies that (i) reduce user fees charged for infrastructure services so as to equate them with their marginal cost; and (ii) increase user fees charged for federally-produced value-added services to include imputed profit and risk.

Table 5: Canadian Public Sector Meteorological Infrastructure – MSC Capital Investment Plan, FY 2001 – 2004.

		2000/2001 (Millions of Current Dollars)	2001/2002 (Millions of Current Dollars)	2002/2003 (Millions of Current Dollars)	2003/2004 (Millions of Current Dollars)	Total
Monitor the Atmosphere	Incremental Capital	21.8	18.3	16.6	14.8	71.5
	Incremental O&M	2.6	2.4	2.7	3.3	11
Warn Canadians of Hazardous Meteorological Events	Incremental Capital	2.5	6.5	5.5	8.1	22.6
	Incremental O&M	12.6	13.1	13.7	14.6	54
Information on Past and Present Climate	Incremental Capital	1	0.7	0.5	0.5	2.7
	Incremental O&M	0.6	0.6	0.6	0.7	2.5
Information on Past & Present Water Quantity	Incremental Capital	5.1	4.1	4.1	4.0	17.3
	Incremental O&M	1.9	2.0	1.9	2.1	7.9
Warn Canadians of Hazardous Lake and Sea Ice	Incremental Capital	1.5	0.0	2.6	2.3	6.4
	Incremental O&M	1.0	1.3	1.3	1.3	4.9
Warn Canadians of Hazardous Air Quality Levels	Incremental Capital	1.4	0.7	0.0	0.0	2.1
	Incremental O&M	0.0	0.0	0.0	0.0	0.0
Science Advice on Climate Change	Incremental Capital	0.7	0.7	0.0	0.0	1.4
	Incremental O&M	0.5	0.6	0.7	0.8	2.6
Science Advice on Air Quality	Incremental Capital	0.5	0.1	0.0	0.0	0.6
	Incremental O&M	0.3	0.4	0.5	0.6	1.8
Total[17]	Incremental Capital	34.5	31.2	29.2	29.7	**124.6**
	Incremental O&M	19.6	20.7	21.7	23.6	**85.6**

[17] Totals based on tabular values may exhibit rounding errors.

Notes to Table 5.
"Environment Canada: Atmospheric Environment Program (Millions) Capital and Operating Requirements", Environment Canada, undated. Note that the program outlined above reflects a one-time submission by MSC to the Treasury Board Program Integrity 1 exercise on July 24, 1999. Out of the total $216 million in incremental capital and associated operating and maintenance dollars requested over five years, MSC has received $20 million (over five years) to address critical occupational and health safety issues. It should also be noted that the proposed investment plan referenced above does not reflect the most current MSC investment planning assumptions. Use of the Program Integrity 1 plan are used here to analyze optimal capital sums required and associated benefits, incremental to the reference levels in 2000/01.

In principle, the optimal infrastructure investment level is that which achieves the maximum economic return on investment. In practice, government departments are limited by the fiscal framework and cannot necessarily receive Cabinet approval for optimal investment amounts. Section 5 assesses the return on investment likely to be forthcoming from the base case investment plan (shown above in Table 5) and examines the case for yet higher levels of investment.

A withdrawal from the provision of value-added services is commensurate with a policy framework in which federal government involvement is guided by the test of market failure. There are different ways in which such a policy framework could be implemented. In the United States, for example, federal policy states that the National Weather Service shall not provide a product or service that the private sector either does, or could provide. An appeals office exists to examine private claims of violation. Alternatively, Environment Canada could examine the detailed cost structure of each of its activities so as to determine whether or not they exhibit economies of scale, non-excludability or other evidence of market failure. The adjustment of user fees to reflect imputed profit and risk represents a third approach. By "levelling-the-playing field" between government and private provision of value-added services, the market would help determine whether a product or service is best provided in the public sector, the private sector or both. Of course, a combination of these three implementation strategies could also be developed.

A policy of federal withdrawal from the provision of value-added added services would need to be implemented with due regard for the time required by private firms to step in. Withdrawing too abruptly would create the risk of U.S. firms stepping in to certain sectors of the Canadian marketplace before domestic firms can establish serious competitive beachheads. On the other hand, once such beachheads were in place, the United States offers a well developed export market. Alternative withdrawal strategies for balancing these risks and rewards are not considered in this study.

4.2 Evaluation Criteria

The study evaluates the major strategic alternatives outlined above in relation to two principal criteria:

1. Economic efficiency (maximum net economic and social benefits); and

2. Promotion of the most efficiently-sized private sector in meteorological infrastructure services.

The evaluation is presented next.

5 EVALUATION OF ALTERNATIVE FEDERAL POLICY DIRECTIONS

Section 5.1 looks first at the business case for Environment Canada's investment plan (as summarized in Table 5 above). We find the expected return on investment to be high, in order of 69.4 percent. One reason for the high rate of return is the large backlog of capital requirements. Delay means that potential benefits have cumulated over the years and are being released through capital investment now.

Section 5.2 asks whether higher levels of capital investment would liberate greater benefits still and whether their incremental economic value would justify the incremental economic costs.

Finally, Section 5.3 assesses the prospective effects of strategic options under which the federal government would withdraw from the provision services that do not exhibit evidence of market failure.

5.1 The Business Case for MSC's Proposed Infrastructure Investment Plan

The infrastructure investment plan shown in Table 5 can be expected to yield both private and social economic benefits. As discussed in previous sections, private benefits arise in the form of enhanced national productivity and Gross Domestic Product. Social benefits arise in the form of values that are not reflected in the national GDP accounts. These include the value of lives saved, injuries avoided, time savings, habitat preserved and so on.

5.1.1 Private Economic Benefits

Based on the econometric model presented in Appendix B, the estimated present-day value of increased productivity and economic output due to the Environment Canada investment plan is $4.5 billion. This assumes a ten-year economic life for new facilities and equipment, a potentially conservative number but one that reflects the risk technological obsolescence as well as normal wear and tear.

5.1.2 Social Benefits

Under the measurement framework presented earlier, the magnitude of social benefits turns on the extent to which new investment is likely to improve the accuracy of weather predictions. Based on an estimated 2.5 percent improvement (see Figure 6) and the earlier estimate of "social benefits per percentage point improvement in forecast accuracy", the present value of the investment plan's projected social benefits is $88.4 million, as shown in Table 6.

5.1.3 Net Economic Benefits

Given the projected benefits outlined above, and expected costs of $280.9 million (present value, in constant 2000 dollars), the investment plan *net present value* is an estimated $4.6 billion. This equates to an internal rate of return of 69.4 percent. Although a return of this magnitude might seem unexpectedly high for a public investment, it is in fact characteristic of returns on public infrastructure projects (such as roads and water facilities) that redress many years of delayed modernization and upkeep. In studies for the U.S. Federal Highway Administration, Nadiri[18] found the return on highway investment in the United States to be 35 percent during the 1970s when the United States was catching up with many years of relative neglect. Returns fell to "normal" levels – about 10 percent – thereafter.

[18] Nadiri, op. cit 1996

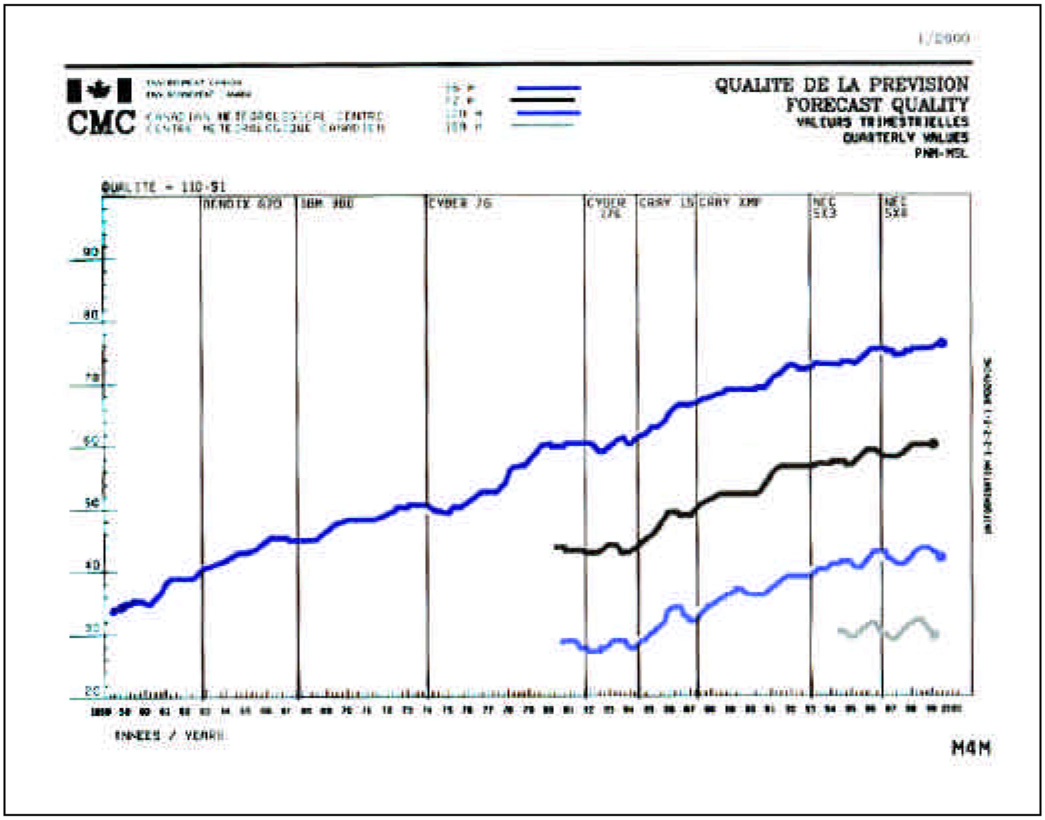
Table 6: Business Case Assessment of MSC Proposed Capital Investment Plan, FY 2001 – 2010 (in constant 2000 dollars).

	00/01	01/02	02/03	03/04	04/05	05/06	06/07	07/08	08/09	09/10	Present Value (10 % Discount Rate)
Costs[19]											
Capital Spending (Millions of 2000 Dollars)	34.5	28.4	24.1	22.3	20.3	0	0	0	0	0	**129.6**
Incremental O&M (Millions of 2000 Dollars)	19.6	18.8	17.9	17.7	16.1	14.7	13.3	12.1	11.0	10.0	**151.3**
Total Cost (Millions of 2000 Dollars	54.1	47.2	42	40	36.4	14.7	13.3	12.1	11.0	10.0	**280.9**
Benefit											
Output (Millions of 2000 Dollars)	0.0	0.0	0.0	0.0	0.0	1,017.7	955.4	896.6	841.0	788.5	**4,499.2**
Social (Millions of 2000 Dollars)	0.0	0.0	0.0	0.0	0.0	21.2	19.3	17.5	15.9	14.5	**88.4**
Total Benefit (Millions of 2000 Dollars)	0.0	0.0	0.0	0.0	0.0	1038.9	974.7	914.1	856.9	803.0	**4587.6**
Net Present Value (Total Benefit – Total Cost) (Millions of 2000 Dollars)											**4,306.7**

Note: The program outlined above reflects a one-time submission by MSC to the Treasury Board Program Integrity 1 exercise on July 24, 1999. Out of the total $216 million in incremental capital and associated operating and maintenance dollars requested over five years, MSC has received $20 million (over five years) to address critical occupational and health safety issues. It should also be noted that the proposed investment plan referenced above does not reflect the most current MSC investment planning assumptions. Use of the Program Integrity 1 plan are used here to analyze optimal capital sums required and associated benefits, incremental to the reference levels in 2000/01.

[19] Environment Canada: Atmospheric Environment Program Capital and Operating Requirements Include Inflation Factors. Note: Assumes a nominal Incremental Capital cost in 2004/2005 of 29.7.

Figure 6: Canadian Meteorological Centre Forecast Quality, 1958 – 2000.



Weather and Environmental Predictions – Business Line Plan, 2000/2001 – 2002/2003, Environment Canada, January 26, 2000.

5.2 The Business Case for Higher Levels of Infrastructure Investment

Although this report does not seek to quantify the theoretically optimal level of meteorological capital investment, simulations with the econometric model presented in Appendix B indicate that the optimal level is greater than that reflected in the Environment Canada investment plan. In other words, up to a certain point, higher levels of capital investment would yield economic benefits in the form of productivity of national output that exceed the incremental capital and operating costs. While more analysis would be needed to provide a detailed estimate, initial simulations indicate that the currently planned level of investment would need to be approximately doubled to achieve maximum efficiency. One means of financing such additional investment would be through the diversion of budgetary outlays presently dedicated to the provision of value-added products and services.

5.3 The Economic Effects of Federal Withdrawal from the Provision of Value-Added Products and Services

The primary effect of Environment Canada's withdrawal from the market for value-added commercial products and services would be:

- A larger number of private firms and privately generated products and services;
- Greater private sector investment and innovation in value-added commercial forecasting products and services; and
- Lower consumer prices for value-added commercial products and services.

5.3.1 Impact on Market Size

Although the timing of market effects would depend upon the rate at which the federal government transitioned out of the provision of value-added commercial services, the long run implications for market size are significant. As shown in the market analysis presented in Table 7 (the underlying technical basis of which is given in Text Box 1), the private sector in meteorological products and services would expand for its current level of about $60 million in total annual revenues to between $186.2 million and $159.6 million annually. If average revenues per firm remain at the current level (of about $2 million a year), the number firms in the Canadian market would expand from about 30 today to more than 110.

5.3.2 Impact on Innovation and Consumer Prices

At the upper end of the range given in Table 7, the value of total private sector meteorological products and services would grow to exceed the total value of such services provided today by the federal government and the private sector combined. The latter figure is $169 million, comprised of $109 million in federally provided products and services (see Table 5) plus the $60 million in privately supplied products and services. As shown in Table 7, the private sector could grow to $186.2 million annually, some 10 percent more than the combined value of federal and private services today. This increase would likely represent a combination of factors, including better prices and thus more demand, but also greater innovation spurred by the additional competition for private business.

Table 7 The Potential Canadian Market for Meteorological Services, by Service and Value (Millions of 2001 Dollars)

Types Of Services	Value-Added Services	Value of Services Supplied by Private Firms under Current Market Structure	Estimated Value of Services Supplied by Private Firms under Optimal Market Structure	
			Low	High
Services Provided by Public & Private Sectors	• Specific R&D • Software Development • Numerical Modeling • Weather Data Analysis • Data Processing & Quality Control • Weather Forecasting • Hydrological Data & Forecasts • Air Pollution • Media • Consultation Services			
Public/Private Partnerships	• Aviation Weather Forecasts • Lightning Detection & Forest Fire Prevention	$55–65	$152.2	$177.5
Services Provided by Private Sector Alone	• Training & Continuous Education • Forensic Meteorology • Micro Climate			
Services Provided by Public Sector Alone	• Weather Data Gathering and Archiving • Weather Warnings (Information) • General Weather Services in Sparsely Populated Areas • R&D	–	$7.4	$8.7
Services Provided by U.S. Private Sector & Not Duplicated by Canadian Private Sector	Though Canadian and U.S. firms tend to specialize in different services, overall the array of services is similar in both countries.	N/A		
Services Provided by U.S. Public Sector Alone	N/A	N/A		
Total Services		**$55–65**	**$159.6**	**$186.2**

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Notes to Table 7: The Potential Canadian Market for Meteorological Services

Value of Services Supplied under Current Market Structure

The annual revenues of Canadian meteorological firms are currently estimated at $55-65 million. The array of services provided in Canada is very similar to the U.S. and we could not identify specific services provided in the U.S. only. Though it is suspected that such additional services exist, they account for a very small share of the market. Therefore, under the current market structure the value of the private Canadian market is **$55-65 million**.

Value of Services Supplied under Optimal Market Structure

To assess the value of the potential Canadian market under an optimal market structure, we need to know the value of services solely provided by the MSC:

- Weather data gathering and archiving: Weather data gathering and archiving are not considered as true value added services. Their value added can be estimated at $2 million approximately.
- Weather warnings (including marine warnings): $3 million (a tenth of weather warnings, forecasts and information). On average, the MSC releases 14, 000 severe weather warnings and half a million weather forecasts annually.
- General weather services in sparsely populated areas: Their value is not known. These services account for a very thin share of the potential market, thus their value is negligible.
- Research and development (excluding marine weather R&D): $8.3 million

As a result, the services solely provided by the MSC have a total value of **$13.3 million**.

These estimates need to be adjusted to account for the potential size of the private sector based on the U.S. experience. Annual revenues of the private sector are estimated by HLB at $1,855–2,616 million. Therefore, the market share of the US private sector lies between **50.9%** and **59.4%**. In Canada, private companies account for only 21% of the market. Furthermore, we can reasonably assume that the Canadian market will expand by about 10% (**$28.5 million**) as a result of the entry of new firms on the market.

The total value of the market for meteorological services is currently estimated at **$285 million**. Thus the adjusted total value of the potential Canadian private market is:

- $285 million * (1+10%) * 50.9% = $159.6 million (low estimate)
- $285 million * (1+10%) *59.4% = $186.2 million (high estimate)

The share of additional services to the private sector (i.e., services provided by the MSC alone under the current market structure) is:

- $13.3 million * (1+10%) * 50.9% = $7.4 million (low estimate)
- $13.3 million * (1+10%) * 59.4% = $8.7 million (high estimate)

The share of services currently supplied by the public and private sectors is:

- $159.6 million - $7.4 million = $152.2 million (low estimate)
- $186.2 million - $8.7 million = $177.5 million (high estimate)

6 CONCLUSION

This study yields four principal conclusions, as follows:

1. Just under three-quarters of the expenditures of Environment Canada's Meteorological Services of Canada ($159 million in fiscal year 2000-01) involve meteorological infrastructure activities and outputs that address a market failure and thus belong in the federal domain. The remaining expenditures, $66.5 million in fiscal year 2000-01, are for the production of value-added services that would be more efficiently provided by private firms.

2. The federal government has permitted the value of the capital stock of meteorological infrastructure to erode over the past 25 years. This erosion has contributed measurably to the nation's sluggish rate of growth in productivity and Gross Domestic Product. Although Environment Canada's proposed $280 million five-year capital investment plan would yield net benefits of $4.6 billion over ten years (a 69 percent rate of return), even higher levels of federal infrastructure investment would be economically justified.

3. MSC charges more than the optimal price (more than marginal cost) for meteorological infrastructure services, thereby preventing the maximization of the economic and social benefits of weather prediction; and

4. MSC does not impute an allowance for normal profit and risk into the prices it levies for its value-added products and services. This places private providers at a competitive disadvantage that limits their growth and inhibits innovation in the private sector supply of such products and services. If the federal government were to withdraw from the provision of products and services in which no evidence of market failure is apparent, the value of private sector output and employment in the production of meteorological services would more than double.

APPENDIX A. HLB ESTIMATION OF THE OUTPUT AND PRODUCTIVITY BENEFITS OF METEOROLOGICAL SERVICES

1. Framework

Consider the production function:

$$Y_t = A_t * f(K_t, L_t, G_t)$$

Where:

Y = real aggregate output of the private sector;
A = a measure of productivity;
K = aggregate stock of non-residential private capital;
L = aggregate employment of labour services by the private sector; and
G = non-military public capital stock, or public expenditures.

Here, we replace G by either a measure of the public stock of capital used in the production of weather services (weather forecasting equipment and the like) or a measure of public spending on weather services (e.g., annual budget of the Meteorological Service of Canada).

A simple estimating equation can be written as:

$$\log(Y_t) = \beta_0 + \beta_1.\log(K_t) + \beta_2.\log(L_t) + \beta_3.\log(G_t) + \varepsilon_t$$

$$\text{or} \quad y_t = \beta_0 + \beta_1.k_t + \beta_2.l_t + \beta_3.g_t + \varepsilon_t$$

We may also consider additional explanatory variables, including:

T = a time trend; and

CU = the capacity utilization rate in the private sector (or manufacturing/industrial sector only), to control for the influence of the business cycle.

$$y_t = \beta_0 + \beta_1.k_t + \beta_2.l_t + \beta_3.g_t + \beta_4.t + \beta_5.cu_t + \varepsilon_t \quad \text{(See Figure A-1)}$$

Following Aschauer, we also estimate a productivity equation, relating output per unit of capital (y - k) to the labour to capital ratio (l - k) and the public capital to private capital (g - k) ratio:

$$y_t - k_t = \beta_0 + \beta_1.(l_t - k_t) + \beta_2.(g_t - k_t) + \beta_3.t + \beta_4.u_t + \varepsilon_t \quad \text{(See Figure A-2)}$$

2. Data Requirement and Data Sources

Data Requirements:

Annual data for Y, K, L, G and CU, for at least 20 years, preferably 30;

All variables are either end-year or mid-year values, we convert end-year to mid-year if needed;

All "money" variables (Y, K, and G) are expressed in constant dollars;

Capital stock data (K and G) are net of depreciation;

The public capital stock (G) is inclusive of federal, state, and local equipment and structures;

L, the aggregate employment of labour services by the private sector, is measured in hours.

Suggested Data Sources:

Most data are found on Statistics Canada website, at http://www.statcan.ca/english/CANSIM.

Variables	Data Sources
Y	Statistics Canada, CANSIM II, Table 379-0004: Gross domestic product at factor cost in 1992 constant dollars, by Standard Industrial Classification (1961-2000)
K	Statistics Canada, CANSIM II, Table 031-0002: Flows and stocks of fixed non-residential capital, by North American Industry Classification System (NAICS) (1955-2000)
L	Statistics Canada, CANSIM II, Table 279-0020: Labour force survey estimates, employment (actual hours worked) by North American Industry Classification System (NAICS) (1976-2000)
CU	Statistics Canada, CANSIM II, Table 028-0001: Industrial capacity utilization rates, by Standard Industrial Classification (1962-2001)
G	Statistics Canada, CANSIM II, Table 031-0002: Flows and stocks of fixed non-residential capital, by North American Industry Classification System (NAICS) (1955-2000)
	Statistics Canada, CANSIM II, Table 379-0004: Gross domestic product at factor cost in 1992 constant dollars, by Standard Industrial Classification (1961-2000)
	Measure of the public stock of capital used in the production of weather services.
	Budget of the Meteorological Service of Canada.

3. Estimation

Overview:

1) We begin by estimating an Aschauer-like equation (output and productivity equations), where G is the total non-military public stock of capital. This allows an assessment of data quality.

2) We replace G in 1) by total non-military public expenditures. Figures A-1 and A-2 present the regression output for output and productivity estimations, while Box A-1 describes the data used in these estimations.

Figure A-1: Estimation of the Impact of Meteorological Infrastructure Capital Stock on Private Sector Output, 1976 – 2000.

Dependent Variable: Log of Private Sector GDP at Factor Cost, 1976 - 2000	
Variable	**Coefficient (t-Ratio)**
Constant	-6.570967 (-1.483427)
Log of Private Capital Stock	0.907837 (2.670732)
Log of Hours Worked	0.446077 (5.129345)
Log of Meteorological Infrastructure Capital Stock	0.179366 (1.964462)
Time Trend (1976 – 1992)	-0.006027 (-0.811807)
Time Trend (1992 – 2000)	0.003848 (0.755341)
Capacity Utilization	0.004523 (4.736274)
Regression Statistics	
R-Squared	0.998576
F-Statistic	2103.083
Durbin-Watson	1.240603

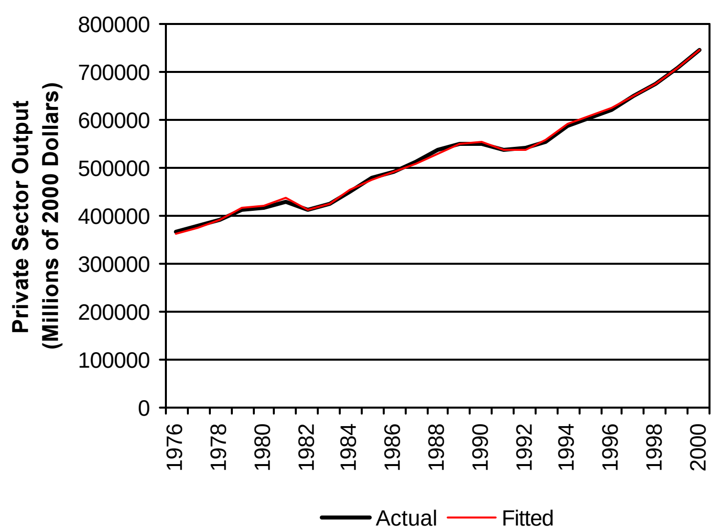

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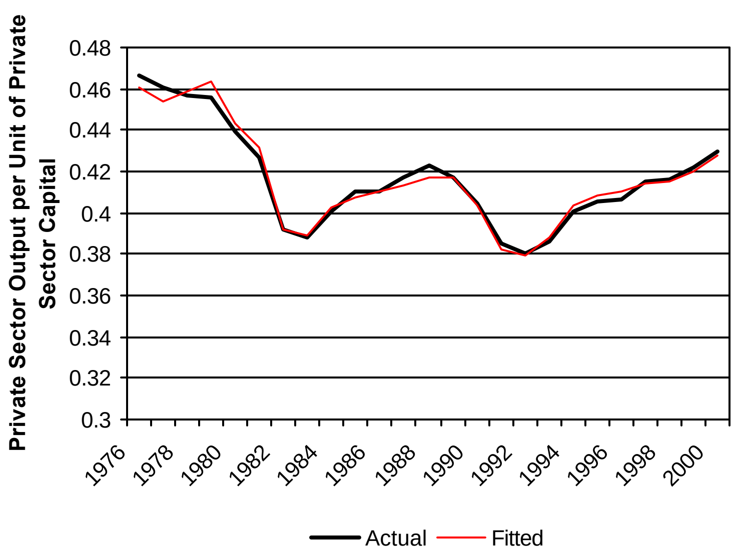
Figure A-2: Estimation of the Impact of Meteorological Infrastructure Capital Stock on Private Sector Output per Unit of Private Sector Capital, 1976 – 2000.

Dependent Variable: Log of Private Sector GDP at Factor Cost *less* Log of Private Capital Stock, 1976 – 2000	
Variable	**Coefficient (t-Ratio)**
Constant	-0.041931 (-0.291178)
Log of Hours Worked *less* Log of Private Capital Stock	0.538751 (10.81978)
Log of Meteorological Infrastructure Capital Stock *less* Log of Private Capital Stock	0.047109 (2.464922)
Time Trend (1976 – 1992)	0.004667 (3.860399)
Time Trend (1992 – 2000)	0.011192 (11.75748)
Capacity Utilization	0.003466 (7.803807)
Regression Statistics	
R-Squared	0.980139
F-Statistic	187.5323
Durbin-Watson	0.963874



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Box A-1: Variable Definitions, Estimation of Private Sector Output and Productivity Impacts

Variable	Description and Source
GDP at Factor Cost	Private sector Gross Domestic Product at factor cost, millions of constant dollars, end-year. Statistics Canada, CANSIM II, Table379-0004
Private Capital Stock	End-year gross capital stock – Canada, Private Sector. Calculated by subtracting Public Capital Stock[1] from Total Capital Stock[2]. Non-residential, millions of constant dollars. **1.** End-year gross capital stock – Canada, Public Sector, non-residential, millions of constant dollars. Statistics Canada, CANSIM II, Table 031-0002. **2.** End-year gross capital stock – Canada, non-residential, millions of constant dollars. Statistics Canada, CANSIM II, Table 031-0002
Private Sector Hours Worked	Actual hours worked - Canada, private employees, all jobs, annual averages, in thousands. Statistics Canada, Labour Force Survey, Program A21187
Meteorological Infrastructure Capital Stock	Gross Capital Stock, Weather services business lines, Environment Canada. Calculated using depreciation rate of 10%[3], reference capital stock of $333,405M in 1998[4], and annual capital expenditures[5]. End-year, millions of constant dollars. **3.** Weather and Environmental Predictions Business Line Plan 2000/2001 – 2002/2003, Environment Canada, January 26, 2000. **4.** "Estimated Value of AEP Assets by Functional Usage", Environment Canada, June 21, 1998. **5.** Public Accounts of Canada, 1976 – 2000.
Capacity Utilization	Industrial capacity utilization rates for manufacturing industries, percent, as an annual average. Statistics Canada, CANSIM II, Table 028-0001
Constant	Equal to 1 in each period.
Time Trend	Equal to 1 in 1976, incrementing by 1 each year.

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Derivation of Business Case Private Benefits Estimates

The estimates of output benefits provided in Section 5 are derived as follows. The results depend upon the theoretical foundation and associated regression results provided above.

1. Forecast independent variables from the productivity regression model for the period 2001 – 2010 (The right-hand side of the equation below, which corresponds to the productivity equation above).

$$Y_t = \boldsymbol{b}_0 C + \boldsymbol{b}_1 L_t + \boldsymbol{b}_2 G_t + \boldsymbol{b}_3 T_{1t} + \boldsymbol{b}_4 T_{2t} + \boldsymbol{b}_5 CU_t$$

2. Use regression results and forecasted independent variables to create a forecast of the dependent variable (the left-hand side of the equation above) under different assumptions (see 3 below) regarding the coefficient on the log of meteorological stock / Capital stock variable ($\boldsymbol{b}_2$ in the equation above).

3. Three estimates are calculated:

   - Regression estimate ($\boldsymbol{b}_2$ = 0.047109)
   - Low estimate = 95% probability that the true coefficient exceeds this estimate ($\boldsymbol{b}_2$ = 0.00964948)
   - Risk-adjusted estimate = 25% of low estimate ($\boldsymbol{b}_2$ = 0.00241237)

4. For each estimate,

   - Calculate the forecast output values under a "no-investment" scenario
   - Calculate the forecast output values under the assumed capital investment stream

5. Benefits from the capital investment are assumed to begin in 2005/06, following the completion of the investment stream. The difference between the two forecasts calculated in 4 is discounted to 2000 dollars (using a discount rate of 10%). The results are detailed in the Table below.

Appendix Table: Estimates of Output Benefit Stream under Three Alternatives

Coefficient Estimate Used	05/06	06/07	07/08	08/09	09/10	Present Value (10% Discount Rate)
Regression Estimate	13,284.8	12,401.7	11,572.4	10,794.1	10,064.3	58,117.2
Low Estimate	3,813.8	3,577.1	3,353.7	3,142.9	2,944.2	16,831.8
Risk-Adjusted Estimate	1,017.7	955.4	896.6	841.0	788.5	4,499.2

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APPENDIX B. HLB ESTIMATION OF SOCIAL BENEFITS

Social Benefits and Externalities	Valuation Unit	Total Events per Year	Total Value of Loss (Valuation Unit * Total Events)	Weather Prediction Improvement Ratio	Loss Reduction/ Year due to Weather Improvement	Benefits Over 30 Years	Source and Comments
Weather Related Gains to Insurance Industry							Report from Small Business Group on Weather and Insurance Industry.
Property and Casualty Claims	$ value of claim	Number of claims					
Crops Damage Claims	$ value of claim	Number of claims					
Life Loss Claims	$ value of claim	Number of claims					
Auto Claims	$ value of claim	Number of claims					
Total Loss/Gain			$4,000,000,000	10.00%	**$400,000,000**	**$12,000,000,000**	
Weather Related Gains to Agriculture Sector							P.G. Aber, "Social and Economic Benefits of Weather Services, Assessment Methods, Results and Applications".
Crop Damage	$ value of per hectare damage	Number of hectares damaged					
Harvesting Loss	$ value of per hectare harvesting loss	Number of hectares not harvested					
Plantation Loss	$ value of per hectare plantation	Number of hectares not planted					
Chemical Spraying Loss	$ value of per hectare loss of chemical spray	Number of hectares affected					
Other Losses	$ value of per hectare damage	Number of hectares damaged					
Total Loss/Gain				10.00%	**$750,000,000**	**$22,500,000,000**	

Social Benefits and Externalities	Valuation Unit	Total Events per Year	Total Value of Loss (Valuation Unit * Total Events)	Weather Prediction Improvement Ratio	Loss Reduction/ Year due to Weather Improvement	Benefits Over 30 Years	Source and Comments
Weather Related Gains to Energy Sector							Report from Small Business Group on Weather and Insurance Industry.
Transmission Lines Damage	$ value of transmission line	Average number of transmission lines destroyed					
Power Poles Damage	$ value of pole	Average number of of poles destroyed					
Steel Towers Damage	$ value of tower	Average number of towers destroyed					
Total Loss/Gain				10.00%	**$200,000**	**$6,000,000**	
Weather Related Safety Gains							
Life Savings	Average $ value of life ($3 million)	Number of lives (3.86 lives)	$11,580,000	10.00%	$1,158,000		In 1987, flood caused 2 people to die in Montreal and tornadoes caused 27 to die in Edmonton. In 1996, flood caused 25 people to die in Canada. Thus over 14 years there were 3 prominent events, or 3/14=0.21 event per year. On average each event caused 18 deaths, or 3.86 deaths per year. Since the price of life is $3 million, the total life loss is $11,580,000 per year. (Small Business Group)
Reduced Accidents	Average $ value of each accident	Number of accidents	$409,508,000	10.00%	$40,950,800		
Injuries	$50,000	2,598	$129,900,000				
Property Loss	$4,000	69,902	$279,608,000				
Total Loss/Gain					**$42,108,800**	**$1,263,264,000**	

Social Benefits and Externalities	Valuation Unit	Total Events per Year	Total Value of Loss (Valuation Unit * Total Events)	Weather Prediction Improvement Ratio	Loss Reduction/ Year due to Weather Improvement	Benefits Over 30 Years	Source and Comments
Weather Related Gains to Forestry							
Reduced Fire Intensity	Cost of each Fire Load Sustained Action ($90)	Average number of FLSA due to lightning (58,112)	$5,230,080	10.00%	$523,008		
Total Loss/Gain					**$523,008**	**$15,690,240**	
Weather Related Gains to Time							
Loss of Flight Diversion	$ value of each flight diversion	Average number of flight diversions	$14,600,000	10.00%	$1,460,000		Assuming 365 flight diversions per year. Each flight diversion costs $40,000. (Small Business Group)
Loss of Flight Cancellation	$ value of each flight cancellation	Average number of flight cancellations	$54,750,000	10.00%	$5,475,000		Assuming 365 flight cancellations per year. Each flight cancellation costs.$150,000. (Small Business Group)
Loss of Delayed Decision	$ value of each delayed decision	Average number of delays	$36,500,000	10.00%	$3,650,000		Assuming 1 delayed decision every day means 365 delays per year. Each delay decision costs $100,000. (Small Business Group)
Total Loss/Gain					**$10,585,000**	**$317,550,000**	
GRAND TOTAL					**1,203,416,808**	**$36,102,504,240**	

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APPENDIX C. ENVIRONMENT CANADA OUTPUTS CLASSIFIED BY INFRASTRUCTURE AND VALUE-ADDED PRODUCTS AND SERVICES

Grand total, all activities (Net Budgetary Expenditures): $160.7 M
Grand total, all activities (Vote Net Revenue): $64.8 M
Grand total, all activities: $225.5 M

Infrastructure Activities	Expenditures (Millions of Current Dollars)		
	Net Budgetary Expenditure	**Vote Net Revenue (excl. EBP)**	**Gross Budgetary Expenditures**
Total	**129.7**	**29.3**	**159.0**
Research & Development	23.6	2.2	25.8
Cloud and precipitation physic	1.9	0.7	2.6
Severe Weather	0.45	0.15	0.6
Climate modeling & Analysis	5.2	0.0	5.2
Climate processes	4.0	0.2	4.2
Ice research	0.0	0.4	0.4
Hydrologic modeling & application development	0.8	0.01	0.8
Stratospheric studies	2.6	0.2	2.8
Atmospheric science based assessment	0.9	0.1	1.0
Atmospheric change adaption	1.5	0.0	1.5
Atmospheric change impacts	0.5	0.08	0.6
Rais on	0.3	0.08	0.4
Management & admin support	3.1	0.0	3.1
Scientific support to R&D	2.3	0.3	2.6

Value Added Activities	Expenditures (Millions of Current Dollars)		
	Net Budgetary Expend-iture	**Vote Net Revenue (excl. EBP)**	**Gross Budgetary Expend-itures**
Total	**31.0**	**35.5**	**66.5**
Research & Development	8.3	1.4	9.7
Numerical Weather Prediction	2.3	0.6	2.9
Data assimilation and satellite	1.7	0.05	1.8
Marine weather research	0.0	0.2	0.2
Climate trends & data analyses	4.3	0.5	4.8
Production	21.4	33.6	55.0
Weather warnings, forecasts and information	10.1	28.2	38.3
Marine warnings, forecast and information	0.3	0.1	0.4
Climate applications, forecast and information	0.6	1.3	1.9
Ice warnings, forecast and information	0.7	2.2	2.9
Hydrological forecasts and information	0.4	0.1	0.5
UV forecasts and information	0.0	0.0	0.0
Nuclear and volcanic modeling	0.2	0.0	0.2
Electronic data processing AES	4.6	1.0	5.6

Infrastructure Activities	Expenditures (Millions of Current Dollars)		
	Net Budgetary Expend-iture	Vote Net Revenue (excl. EBP)	Gross Budgetary Expend-itures
Monitoring Infrastructure	**47.3**	**22.3**	**69.6**
Land-based surface networks	3.2	2.6	5.8
Aerological network	7.0	0.03	7.0
Radar network	6.4	0.2	6.6
Satellite network	0.0	0.0	0.0
Lightning network	0.1	1.2	1.3
Marine network	0.8	0.0	0.8
Other data	0.0	0.0	0.0
Inspection & maintenance	8.3	2.7	11.0
Engineering & technical support	3.0	1.0	4.0
Network planning	2.1	0.01	2.1
Climate network	0.5	0.0	0.5
Ice reconnaissance data	0.9	3.1	4.0
Inspection & maintenance (ice)	0.001	0.0	0.001
Engineering & technical support (ice)	0.6	4.7	5.3
Network planning (ice)	0.0	0.0	0.0
Water quality & quantity network	8.2	5.4	13.6
Inspection & maintenance (water)	1.5	1.1	2.6
Engineering & technical support (water)	1.19	0.012	1.2
Network planning (water)	0.8	0.0	0.8
Stratospheric Ozone/UV network	0.0	0.0	0.0
Archive & quality control	1.2	0.06	1.3
Management & Admin Support	1.5	0.2	1.7

Value Added Activities	Expenditures (Millions of Current Dollars)		
	Net Budgetary Expend-iture	Vote Net Revenue (excl. EBP)	Gross Budgetary Expend-itures
Electronic data processing regions	1.4	0.1	1.5
upport to the warning production ystem	0.2	0.1	0.3
roduct development	0.2	0.1	0.2
Management & admin support	1.6	0.5	2.1
Other support	1.0	0.0	1.0
Service Delivery	**1.3**	**0.5**	**1.8**
Client consultation and feedback	1.2	0.5	1.7
Environment assessment	0.1	0.0	0.1

Infrastructure Activities	Expenditures (Millions of Current Dollars)			Value Added Activities	Expenditures (Millions of Current Dollars)		
	Net Budgetary Expend-iture	**Vote Net Revenue (excl. EBP)**	**Gross Budgetary Expend-itures**		**Net Budgetary Expend-iture**	**Vote Net Revenue (excl. EBP)**	**Gross Budgetary Expend-itures**
Production	42.8	0.0	42.8				
Weather warnings, forecasts and information	20.1	0.0	20.1				
Marine warnings, forecast and information	0.6	0.0	0.6				
Climate applications, forecast and information	1.2	0.0	1.2				
Ice warnings, forecast and information	1.5	0.0	1.5				
Hydrological forecasts and information	0.8	0.0	0.8				
UV forecasts and information	0.1	0.0	0.1				
Nuclear and volcanic modeling	0.3	0.0	0.3				
Electronic data processing AES	9.1	0.0	9.1				
Electronic data processing regions	2.7	0.0	2.7				
Support to the warning production system	0.5	0.0	0.5				
Product development	0.4	0.0	0.4				
Management & admin support	3.2	0.0	3.2				
Other support	2.0	0.0	2.0				
Service Delivery	21.4	33.6	55.0				
Dissemination and special delivery system	0.9	3.3	4.2				
Dissemination system design	0.0	0.4	0.4				
Public out reach and education	0.1	0.002	0.1				
Management and admin support	0.3	0.004	0.3				

Infrastructure Activities	Expenditures (Millions of Current Dollars)			Value Added Activities	Expenditures (Millions of Current Dollars)		
	Net Budgetary Expend-iture	Vote Net Revenue (excl. EBP)	Gross Budgetary Expend-itures		Net Budgetary Expend-iture	Vote Net Revenue (excl. EBP)	Gross Budgetary Expend-itures
National Support Systems	21.4	33.6	55.0				
Telecommunication general	3.2	0.3	3.5				
Telecommunication water	0.0	0.0	0.0				
Business planning	0.3	0.0	0.3				
Evaluation and performance measurements	0.4	0.0	0.4				
Policy, liaison & international affairs	0.0	0.8	0.8				
WMO assessment	0.2	0.0	0.2				
Communication support to WEP	0.2	0.0	0.2				
Training and development	1.1	0.0	1.1				
Management and admin support	0.6	0.0	0.6				
WEP senior management	2.7	0.0	2.7				
Management support to senior WEP management	6.0	0.0	6.0				

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