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Sustainability of Canada's Forest Sector: Estimating Economic Depreciation of Canada's Timber Resources

by

Satoshi Tamai ©

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Abstract

With increasing public concerns over sustainable development, the incorporation of environmental and natural capital into national accounting system is one of the most important challenges to be investigated in economics. This study estimated economic depreciation of Canada's timber resources for 1970-93. Two main methods are used to calculate the depreciation: the net price approach and the Vincent-Hartwick approach that accounts for the age-class distribution in Canada's forests. This study also shows the measurement of Canada's forest sector's sustainability using weak sustainability indicators: environmentally adjusted NDP and net investment. It is very difficult to conclude whether or not Canada's forest sector was sustainable during the period since two weak sustainability indicators provide different conclusions.

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Chapter 1 Introduction

1.1 Introduction

1.1.1 Introduction

Canada is a resource-rich country. In particular, it might be characterized by large areas of forestlands. Despite the increasing interest in integrating assessments of the degradation (or improvement) of Canada's forest resources into national accounting systems, very few studies have been conducted on this subject. Evaluations of changes in the volume and quality of Canada's forest resources over time provide essential information to adjusted forest resource accounts and, furthermore, economically and ecologically sustainable management of Canada's forests.

The interest in incorporating assessments of changes in environmental and natural resource conditions into national accounting systems has brought increasing criticism to traditional national income measures as key measures of a nation's economic and social performance (Peskin 1991, Bartelmus 1999). The underlying assumption in traditional economic measures of economic performance is that natural assets are limitless free goods and services. This might have been an acceptable assumption in the past.

However, the scale of economic activity is at the point where natural resource depletion and environmental degradation have begun to exceed a level that can be sustained (Costanza 1991). The omissions are expected to be a serious distortion in the information contained in the conventional national income measures on true income and economic wealth and welfare (Hassan 2000). Given the need to assess the sustainability of regional, national, and global economies, the development of sustainability indicators such as environmental accounts would be an important step toward sustainable development policy.

Environment and economic activity interact. If economically and ecologically sustainable development is to be taken seriously, then natural resource depletion and environmental degradation must be explicitly incorporated into economic evaluations when calculating the true gains and losses from economic activities. In this sense, the natural resource accounting framework provides a modified measure of traditional national income to reflect reality more fully with regard to the cost of environmental depletion and degradation due to economic activities. This might be an important source of information for formulation of appropriate economic policy design and development planning that avoids serious and irreversible environmental consequences and mismanagement of the natural resource base.

1.1.2 Shortcomings of SNA

According to Sadoff (1995), traditional national income accounts, such as gross product measures or GNP and GDP, are designed to record a systematic and consistent set of data of the production, distribution, and use of goods and services during a specified time. The System of National Accounts (SNA) was first standardized by the United Nations in 1968. The SNA68 recommends that both flow accounts and balance sheet accounts be compiled through satellite accounts that describe the flows of resources, materials (including pollutants), and energy that underlie any economic activity (Peskin 1991).[1] In the words of Solórzano et al. (1991), "This has become the basis for almost all macroeconomic analysis, planning, and evaluation. Therefore, it is expected to be an integrated, comprehensive, and consistent accounting framework" (p.1).

In traditional national accounting systems, only man-made capital depreciation is estimated, and then deducted from the gross product measure in order to measure net national income: The net national product (NNP) is GNP less man-made capital depreciation. Likewise, the net domestic product (NDP) is GDP less man-made capital depreciation. However, when natural capital is depleted or degraded, no analogous depreciation is recorded in national income accounts. Nor are any activities that increase the stock of natural resources defined as capital appreciation.

It is clear that traditional national income measures substantially overstate the true national income if adjustment for depletion and degradation of natural capital is not undertaken. As pointed out by Repetto et al. (1989): "a country could exhaust its mineral resources, cut down its forests, erode its soils, pollute its aquifers, and hunt its wildlife and fisheries to extinction, but measured income would not be affected as these assets disappeared" (p.2).

1.2 Movements toward Natural Resource Accounts

While environmentally adjusted national income accounts have increasingly called attention to the shortcomings of traditional national income measures, the United Nations Statistical Office (UNSTAT) developed the satellite System of integrated Environmental and Economic Accounting

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[1] Flow accounts keep track of transactions during intervals of time such as purchases of goods and services, payments to wage and profit earners, import payments and export revenues for goods and services. On the other hand, balance sheet accounts (or stock accounts) identify assets and liabilities at particular points in time.

(SEEA) in 1993 (Bartelmus et al. 1993, Bartelmus 1999). The framework provided the basis for the United Nations *Handbook on Integrated Environmental and Economic Accounting*. It also presented guidelines for the environmentally revised SNA with regard to the use of natural resources and the change of environmental quality resulting from not only economic activity but also natural events and environmental protection and restoration.[2]

The revision recommended that NDP be given greater emphasis in the environmental analysis. The revised accounting system recommends the integration of flow accounts and balance sheets. In the SNA68, balance sheets were provided separately, but not incorporated in the main accounts. The revised balance sheets include two accounts for presenting the use of natural resources and the change of environmental quality, which are not adequately addressed in the SNA68 (Sadoff 1995). In addition, the SEEA would be broader modified environmental indicators than the SNA and would cover all environmental assets, which are affected by economic activities, in the forms of both physical and monetary accounts.[3]

While the movements of the revised SNA and the SEEA developed by the United Nations lead toward the environmentally modified national income accounts, it raises the practical problem of which valuation methodology is appropriate to estimate the cost of natural resource depletion and environmental degradation. *The Handbook on Integrated Environmental and Economic Accounting* recommends several methods for valuing stocks of natural resource and environmental assets in the accounting period (Vincent and Hartwick 1997, Common and Sanyal 1999, El Serafy 1999).[4] Among them, two approaches are most commonly discussed in the literature on economic rent calculation: the user cost approach, also known as El Serafy's user cost approach, and the net price approach (El Serafy 1999). In this analysis, only the net price approach will be focused on estimating economic depreciation in Canada's timber resources as a simpler and more practical approach than El Serafy's user cost approach.

Non-marketed forest-related goods and services remain outside the scope of this analysis. The calculation of 'option' or 'existence' values of these non-timber assets, for whose availability individuals may be willing to pay, do not seem to be applicable in the recurrent national accounting system (Bartelmus 1999). Many articles have already provided extended treatments of valuation methods applied to non-timber user and non-user service values of forests. There are a number

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[2] Several pilot studies based on the SEEA have been completed for Mexico (van Tongeren et al. 1993), Papua New Guinea (Bartelmus et al. 1993), and the Philippines (Bartelmus 1999).

[3] Note that, as an important feature, the SEEA remained as just supplement of the SNA and do not modify the core framework of the SNA, nor do they affect a consistent base with time series data. In addition, changes in the balance sheets, which were not caused by economic activities, are kept in special conciliation accounts.

[4] In the handbook, "three main approaches can be distinguished for the market valuation of stocks of natural assets, - actual market prices of natural assets (the user cost method), present value of expected net proceeds (the net present value method), net prices multiplied by the relevant quantity of the stock of natural assets (the net price method)" (Common and Sanyal 1999 p.368).

of experimental case studies limited to specific regions such as forest management agreement reserves, wildlife species in specific habitats, and non-timber user service values such as hunting, birdwatching, and hiking, for which there are physical and monetary data available.

However, there is no estimation of non-marketed forest values at a national level, so far, due to the difficulties and/or cost constraints involved in quantifying all attributes of Canada's forests. Therefore, in this analysis the value is assigned only to timber removed from Canada's forests. In this sense, this analysis does not give any extensive treatment of forest resource accounts, but is limited to timber resources. Needless to say that this clearly understates the true gain and loss in the social value associated with forest resource assets.

A number of country studies have also been undertaken by the United Nations, the World Bank, and other respective international institutions such as the World Resources Institute to identify the costs and benefits of environmentally modified national income accounts. Case studies of this type have been completed for Indonesia (Repetto et al. 1989), China (Liu 1998), Costa Rica (Solóranzo et al. 1991), Papua New Guinea (Bartelumus et al. 1993, 1994), the Philippines (Bartelmus 1999), Thailand (Sadoff 1995), Zimbabwe (Adger and Grohs 1994, Crowards 1996), and several other countries. These studies have made valuable contributions to resource accounting methodologies through identifying practical difficulties, and have clearly illustrated the deficiencies of traditional SNA and reliance on it as a tool in making environmental and resource policy decisions (Haener 1998).

1.3 Canada's Movements toward Natural Resource Accounts

Today, most OECD countries and an increasing number of other countries have established resource accounting systems in their central statistical offices that supplement their traditional SNAs (Peskin and Lutz 1993, Statistics Canada 1994). Canada is among those countries. However, as pointed out by Haener (1998), depending on which adjustments to the SNA a country identifies as most important for their needs, countries have proposed resource accounting frameworks with different combinations of the modifications outlined in the SEEA. Hence, there is not any single internationally comparable accounting system.[5]

Canada is a resource-rich country with large areas of forestlands, rich mineral deposits, diverse wildlife, and extensive offshore resources (Smith 1994). Generally, those rich natural resources have been taken for granted and treated at most as free goods and services. However,

[5] Peskin (1991) argues that none of the systems will satisfy all the critics of traditional national income accounts. Moreover, there is no "best" system that reflects individual countries' needed data availability.

this approach cannot be continued indefinitely, and Canada's national accounting system must be changed so that it reflects the true nature of the natural resources and environment.

At the national level, the Environment and Natural Resource Division at Statistics Canada has applied the statistical framework with environmental components, such as natural resource accounts in both physical and monetary terms, physical resource use and waste output accounts in physical terms, and environmental protection expenditure accounts (Statistics Canada 1997). Broadly, the natural resource accounts are based on highly disaggregated data on the quantity and quality of natural resources, covering stocks, stock changes due to discoveries and natural growth, and flows. According to Smith (1994), Statistics Canada put their first priority on constructing natural resource accounts of oil and gas reserves and timber stocks, two of Canada's important natural resources. However, this ongoing work by Statistics Canada is focused on constructing a satellite account to the SNA, not in directly modifying Canada's traditional accounting system (Hamilton 1996). Moreover, while valuation of non-market goods and services is considered, it still remains a subject that requires further research (Statistics Canada 1997).

Some valuations of natural resources are actually estimated in monetary terms in Canada. For example, Statistics Canada (1997) provides Canada's timber asset value[6], which is obtained by multiplying the standing stock times the net price, at both national and provincial levels covering the period 1961-90. Gravel, as part of the project initiated by Statistics Canada, also presents the estimates of the timber rents at both national and provincial levels for 1961-95.[7]

Another attempt to develop the natural resource accounting framework in Canada is the program coordinated by the Institute for Research on Environment and Economy (IREE) at the University of Ottawa.[8] As summarized by Friend and Rapport (1991), the primary purpose of the program is to propose "a conceptual framework which tracks stocks and flows of natural resources, incorporates a critical set of indicators of ecological integrity at the eco-region level, and has the capacity to integrate certain parameters in the SNA" (p.59).

Friend and Rapport (1991) suggest the two methods of environmental reportings: Natural Resource Accounting (NRA) and the State of Environment (SOE) Reports, as key indicators of environmental sustainability. The latter focuses on spatially disaggregated qualitative states, while the former focuses on the aggregated quantitative states. However, these environmental reporting

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[6] Statistics Canada (1997) set asset value equal to the discount sum of future rents. For sustainably managed forests, Statistics Canada assumed that future annual flows of rents would equal current flows and so simply divided current annual rent by the discount rate to get the capitalized value. However, according to Vincent and Hartwick (1997), it is less understandable for Canada's case, which had access to detailed data on forests by age class.
[7] This rent value is provided by A. Pearson, M.Sc. student at the Department of Rural Economy at the University of Alberta. These numbers are not published in Econnections, Statistics Canada (1997).
[8] The program was started by Statistics Canada in the mid-seventies.

methods have yet to achieve the same level of acceptance that is currently enjoyed in social and economic reporting because of difficulties of collecting necessary physical data. This problem is exacerbated by uncertainty of complex ecological systems. In addition, this framework is unable to express changes of environments in monetary terms. These reasons make it difficult to support analysis of environmental trends with reliable statistics, while it would appear there are some advantages that the NRA and the SOE Reporting do provide much of physical data needed to fulfill many of the resource accounting objectives of Statistics Canada (Friend and Rapport 1991).

At the regional level, some case studies have been completed for Alberta timber resource accounts 1979-90 (Anielski 1991, 1992, 1994), Ontario timber resource accounts 1953-91 (Moll and Lawrance 1992), British Columbia timber resource accounts 1979 (Percy 1986), the Vancouver Island region natural resource accounts (Prudhan and Lonergan 1992), and northern Alberta forest resource accounts 1996 (Haener 1998). According to Vincent and Hartwick (1997), the research for the Alberta timber resource account by Anielski is the first Canadian application of natural resource accounts. This was conducted as part of a broader resource accounting initiative led by Alberta Treasury and Alberta Environmental Protection, to develop resource accounts for oil and gas, coal, agricultural soils, forests, carbon, and water (Haener 1998). Anielski (1992, 1994) uses the net price method for incorporating natural resource and environmental capital accounts into the traditional SNA.

Most of the regional level studies focus on one, or at most a few, specified natural resource(s) in the context of regional (or provincial) sustainability. On the positive side, the regional scale is more appropriate for public participation and community involvement in resource management planning (MacDonald et al. 1999). In addition, those studies present good data and particular information in analyzing the specific natural resource(s) with implications for regional sustainability.

However, the regional level studies might present unanswered spatial and temporal scale questions. For example, how important is sustainability in a small (eco)region in the context of sustainability issues at the national level or global level across generations? How could valuation derived from environmental component(s) at one spatial and temporal scale level be generalized at different scale levels?

The generalization of income accounts to include environmental and natural components based on the information from a regional level study might be used to value environmental components at totally different spatial scale levels. However, the generalization process has to be done carefully because ecosystems are complex and there are conceptual issues regarding substitution of environmental components across space that have yet to be resolved. For example, we would obtain high depreciation values if we were to constraint adjusted accounts for a heavily harvested area, but this would not yield any perspective on Canada's sustainability issue. Hence, in this study, we aim to study economic depreciation of Canada's forests as a whole and there are deducted from the national GDP. The national forest sector accounts are modified to provide a national forest sustainability indicator.

1.4 Thesis Objectives and Outline

The thesis has two principal objectives. The first objective is to review the concepts of sustainability and presents the definition of sustainability and the methods of measuring sustainability. The second objective is to develop a natural resource accounting framework for incorporating economic depreciation of Canada's timber resources into traditional national income accounts. The sustainability of Canada's forest sector is also measured by using sustainability indicators. This analysis contributes towards correcting traditional national income measures in order to convey more accurate information to designers and planners for sustainable management of Canada's timber resources.

Chapter 2 discusses two major concepts of sustainability: weak sustainability and strong sustainability, particularly subscribed to by ecologists. The chapter consists of critical literature reviews of operational definitions and indicators of both concepts of weak and strong sustainability. It also provides a discussion of both theoretical and practical problems encountered in using both concepts of sustainability. It is argued that the criteria of weak and strong sustainability have respective strengths and limitations.

Chapter 3 includes the estimation of economic depreciation of Canada's timber resources during the period 1970-93 and the measurement of the sustainability of Canada's forest sector. Because of data limitations, no attempt was made to correct for estimation associated with non-marketed forest-related goods and services, such as wildlife species of animals and plants, biodiversity, environmental control functions (e.g. air purification and carbon sequestration), and so on.

In this chapter, two approaches are discussed to calculate economic depreciation of Canada's timber stock: the net price approach, and the Vincent-Hartwick approach. The net price approach includes the correct version of taking into account growth stock effects. The Vincent-Hartwick approach uses a method that accounts for various ages of timber stocks and incorporates the notion of the optimal rotation age. This is followed by a discussion of the imputed results by each method and the measurement of Canada's forest sector's sustainability by using weak sustainability indicators.

The final chapter, Chapter 4, summarizes the findings in Chapter 3, and recommends future avenues for research.

Chapter 2 Theoretical Background toward Natural Resource Accounts

2.1 Concept of Sustainable Development

Sustainable development has become an important concept in development and environmental policy since the publication of the World Commission of Environment and Development's Report, *Our Common Future*, in 1987. The famous principle of sustainable development defined by the Brundtland Report is that "sustainable development seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future" (WCED 1987 p.40).

Shortly after the Brundtland Report first appeared in 1987, it was regarded as a political feat because it obtained almost worldwide political consensus (Common 1996, Goodland 1995). However, while successful as a political statement, implementation of sustainable development policies has been difficult partly because the definition of sustainability remains ambiguous due to its multifaceted characteristics, which touch upon nearly all areas of social, environmental, and economic development (Veeman 1989). Hence, the definition of sustainable development has been interpreted differently by various social and physical sciences.

2.2 Conditions for Sustainability

Based on the Brundtland Report, sustainable development is operationally defined as non-declining welfare over time (Pearce et al. 1996). Proponents of both economic and ecological sustainability would broadly agree with this definition. However, there is no consensus with regard to the conditions required to satisfy the achievement of sustainable development. In the economic paradigm (or weak sustainability), the operative constraint of sustainability ensures non-declining levels in aggregate capital assets such as man-made capital and natural capital with adequate compensation in the form of investments. In this sense, weak sustainability includes all components related to welfare, without determining any specified component of natural capital assets. In the paradigm of strong sustainability, particularly subscribed to by ecologists, the non-declining welfare criterion is achieved only by non-decreasing natural capital assets such as forestlands, fisheries, agricultural lands, wetlands, atmosphere and stratosphere in physical terms.

The distinction between weak sustainability and strong sustainability is an assumption about the degree of substitutability between man-made capital and natural capital (Reynolds 1999). While the former emphasizes the high degree of substitutability between man-made capital and natural capital, the latter denies any substitutability between both types of capital and stresses the integrity of ecosystems (Pearce et al. 1996).[9] Needless to say, even if we accept man-made and natural capital are to some degree substitutable, it is a clear that there is difficulty in determining the degree of substitution precisely because of data availability. (Cabeza Gutés 1996).

Technological change presents further complications in determining the degree of substitutability. Technological change generally enables societies to create efficiencies that increase substitutability over time. Hence, policy makers may also need to forecast substitutability to make appropriate policy. However, technological change is not explicitly assessed in weak sustainability (Cabeza Gutés 1996). For example, Pearce and Atkinson (1995) mention the need to modify their weak sustainability indicator for technological change, since "in the event of technological change, constant capital stock would leave future generations with higher well-being than present generations, as the capital stock is more productive .... technological change would be consistent with a declining capital stock and negative saving" (p.176).

2.2.1 Operational Definition of Weak Sustainability

The principle of weak sustainability is to keep non-declining levels in the overall stock of capital across generations, with the assumption of unlimited substitutability between man-made capital and natural capital. If the overall stock of capital as the operative constraint falls, then the income ability of future generations to meet their own needs is reduced. On the other hand, if the stocks of natural capital are exploited to increase the stock of man-made capital, then the income ability of future generations will be maintained. Weak sustainability implies there is no need for constraints to conserve certain components of the natural/environmental capital stock.

The income required to maintain future generations' welfare is generally called sustainable national income. In a number of works related to resource and environmental accounts, sustainable income is generally defined as:

$$Y_{sus,\,t} = Y_t - D_{kt} - D_{nt} = C_{max,\,t} \qquad (1)$$

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[9] Weak sustainability treats natural capital as a homogeneous form of capital, distinct from man-made capital. Substitutions are considered on the basis of setting degrees of substitutability between these two capital forms. On the other hand, strong sustainability emphasizes that natural capital assets hold different functions with human welfare and thereby identifies critical disaggregate components of natural capital.

where $Y_{sus,t}$ = sustainable income in year t; Y_t = income; D_{kt} = the depreciation value of man-made capital; D_{nt} = the depreciation values of natural capital; and $C_{max,t}$ = the maximum level of consumption consistent with non-declining wealth.

In short, sustainable income is a residual income after reflecting the depreciation values in the man-made and natural capital stocks. This is recognized as a better measure of national income than gross national product (Common 1996). The traditional national income measures, GDP and GNP, do not allow for the depreciation of natural capital stocks, as well as that of man-made capital stocks and therefore tend to treat consumption of natural capital flow simply as a part of income (Goodland 1995). Hence, these traditional measures will overstate sustainable national income. Contrary to these traditional measures, sustainable income provides us with the level of income that determines the maximum level of consumption that can be sustained without jeopardizing the future generation's income or welfare (Solow 1986).

There is a consensus in various literatures that this sustainable income is consistent with the Hicksian notion of income. That is, any income based on declining national wealth should not be counted as a 'true' indicator of welfare. If the level of consumption (C_t) is equal to or less than sustainable income ($Y_{sus,t}$), $C_t \leq Y_{sus,t}$, then the level of consumption is sustainable. If $C_t > Y_{sus,t}$, then the level of consumption is not sustainable. These relationships derived from the sustainable income formula *(1)* are a different way to state the so-called Hartwick's rule (Common 1996).

Hartwick (1979) states that if investment in man-made capital is equated with the value of natural resource depletion and environmental degradation over time, then the economy could sustain constant per capita consumption paths over time.[10],[11] This would guarantee that national wealth is kept constant since the maximum level of consumption is determined to be less than or equal to sustainable income. In other words, sustainable consumption or income is the equivalent of the interest on the constant total wealth, which is composed of natural capital stocks and man-made capital stocks (Solow 1992).

2.2.2 Operational Definition of Strong Sustainability

Strong sustainability requires maintaining non-declining natural capital. In strong sustainability, disaggregated natural capital plays different functions, such as resource supply,

[10] Hartwick (1977) shows this is in the context of exhaustible resources. However, Hartwick's rule is applicable to renewable resources as well as non-renewable resources, although sustainability can not assured for non-renewable resources.
[11] Hartwick's rule relies on other strong assumptions: 1) constant population; 2) convex and stable technology and preference over time; and 3) the existence of relevant shadow prices.

waste assimilation and a variety of ecological services, as distinct components of the life support systems (Pearce and Turner 1990). This feature is not shared with man-made capital. One important gross disaggregation of natural capital is generally between critical and non-critical natural capital, even though identifying whether or not each natural capital component is critical is not an easy task (Cabeza Gutés 1996, Reynolds 1999). Another important disaggregation involves classification of natural capital into such categories as renewable resources, non-renewable resources, and ecological services.

For the management of renewable and non-renewable resources, Pearce (1987) suggests three operational principles that characterize sustainable use of these resources. First, harvest rates of renewable resources should equal regeneration rates. Second, waste emission should equal the natural assimilative capacities of the ecosystems. Third, non-renewable resources should be exploited in a quasi-sustainable manner by limiting their rates of depletion to the rate of creation of renewable substitutes. The quasi-sustainable manner requires that receipts from depleting non-renewable resources should be adequately invested in renewable substitutes.[12]

These arguments stress that man-made capital and natural capital are basically complementary and only very marginally substitutable (Daly 1990). Among particular components of natural capital, substitutability for ecological services is clearly denied, which is directly related to the life support functions of ecosystems such as maintenance of climate regulation, watershed protection, the maintenance of biodiversity, and so on (Costanza 1991, Pearce and Atkinson 1995, Goodland 1995). Based on this complementarity of man-made and natural capital, advocates of strong sustainability insist that growth or development of an economy should be limited by a finite ecosystem and the need for consideration of many irreversibilities and uncertainties.

The insistence that the ecosystem as a source of natural resources and an absorber of wastes is finite involves biophysical limits of economic activity and the relevance of the laws of thermodynamics to economic process (Veeman 1989). Along the lines introduced by Georgescu-Roegen (1971, 1973), the laws of thermodynamics are known as the law of conservation of matter-energy (the first law) and the law of entropy (the second law). The first law states that economic activity cannot create or destroy matter-energy, but can only rearrange it continuously. Therefore, the material exploited in economic activity returns to environment, while being in unchanged mass, but in the forms of residuals (Veeman 1989, Victor 1991).

[12] According to Daly (1990), the idea is to divide the net receipts from non-renewable resources into an income component that can be consumed currently every year, and a capital component that must be invested in the renewable substitute. El Serafy (1989) has shown how this separation is done.

While the first law and its implication are commonly accepted as a fact by economists and ecologists, the law of entropy and its implication are rarely mentioned by economists (Daly 1987, Veeman 1989, Lawn 1999). In the entropy law, according to Victor (1991), economic activities take valuable low-entropy inputs and convert them into valueless high-entropy waste outputs. This results in continuously increasing entropy in a closed thermodynamics system. However, as stated by Veeman (1989), "Any discussion of the relevance of the entropy law to economic activity raises extremely profound and difficult issues" (p.879) because economic activity could be limited by a lack of low entropy matter-energy. Economic activity is not isolated, but supported by a material resource base (environmental low entropy) which is subject to definite constraints. But, as a practical issue, how finding and how impeding are such material resource constraints?

If everything were recycled, the entropy constraints would not be so limiting. However, entropy prevents 100 per cent recycling within a closed system. For instance, when economic activity exploits non-renewable resources such as oil, gas or coal for energy uses, the resource inputs (highly organized low entropy matter) are rearranged into waste outputs such as chemical gases and particles (unstructured high entropy matter). The energy dissipated as useless can no longer be used to rearrange matter. The higher the entropy, the less possibilities for recycling and the less chances of preventing valueless waste outputs from entering the environments. Hence, the increasing rate of resource low entropy input and high entropy output (for the rate of production and consumption of man-made capital) is not maintained without increasing the rate of environmental depletion and degradation (Daly 1987). In entropy terms, any such activity necessarily results in a deficit of any biological enterprises (Georgescu-Roegen 1973).

As stated by Pearce and Atkinson (1995), while man-made capital is reversible in terms that the capital stock can be increased or decreased within biophysical limits, natural capital includes some irreversible assets. The asymmetry characteristics between man-made and natural capital lead to non-substitutability assumptions in strong sustainability. If we make a mistake, then we may never recover to the former state. The extinction of species (i.e. loss of genetic stock) is an obvious case, but the same holds true for certain kinds of land use conversions (e.g. loss of authentically valuable landscapes) and severely disturbed ecosystems.

These irreversible losses of natural capital narrow the potential reserve of genetic materials in existence and the life support functions of the ecosystem. The increased economic activities worldwide are certainly increasing the pace of losses (or extinction) of species and degradation of ecological services compared with the past. Some biologists predict that perhaps one-quarter of existing species are at risk of extinction in the next twenty or thirty years (Pearce and Warford 1993). Indeed, we cannot expect technological advance to compensate irreversible losses of natural capital very well. It is difficult to image technological progress advancing to the point where extinct species could be resurrected with DNA technology, or that grand scenic landscapes could be replicated.

Uncertainty also creates different roles for man-made and natural capital. According to Costanza (1994), uncertainty is referred to as a future state of natural environment with unknown probability at the moment the current economic activity is undertaken.[13] This essentially comes from our incomplete knowledge about natural capital assets, while knowledge about machines tends to be relatively complete. Protecting biodiversity provides a good example of scientific uncertainty. In regards to biodiversity loss, there is clearly uncertainty about the current situation and future prospects (Common 1996). For example, we cannot accurately predict how much the loss of one species affects the local ecosystem, in which the species used to exist. In addition, it is unknown how many species currently exist on Earth or even on the small scale of the local ecosystem, while there is little doubt that these are much larger than the number of species identified currently.[14] While we know a little about species that are currently regarded as directly useful as production inputs, we do not know about many species going extinct. Many of these unknown species may turn out to be regarded as useful one day in the future (Pearce and Warford 1993).

Furthermore, another type of uncertainty – social uncertainty that is linked with unpredictable changes in social (or human) attitudes towards and knowledge of natural capital, would make the uncertainty issue more complicated. The existence of irreversibility and uncertainty together should make us more cautious about giving up natural capital under the assumption of non-substitutability for man-made capital. Assuming people are averse to irreversible losses in natural capital, there is a good reason to avoid declining stocks of natural capital unless the benefits from exploiting or destroying natural capital are known. This perspective leads to the precautionary principle (Perrings 1991, Costanza et al. 1994, Turner et al. 1994, Francis 1996) and the safe minimum standard principle (Ciriacy-Wantrup 1952, Krutilla 1967, Bishop 1978, and Crowards 1998).

2.3 Measuring Sustainability: Sustainability Indicators

2.3.1 Introduction

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[13] In this sense, uncertainty is distinguished from risk which is the future state with a known probability. Therefore, risk analysis is not appropriate to calculate the potentially irreversible impact to natural environments due to current economic activity (Costanza 1994).

There is a large body of literature establishing different candidate indicators for sustainable development. These indicators attempt to capture some important aspects of sustainable development (e.g. economic and ecological aspects). It seems unlikely that there exists one single measure, which is capable of capturing all that is meant by sustainability (Hanley et al. 1999). However, in this section, two major classes of sustainability indicators: weak sustainability indicators and strong sustainability indicators will be described based on the concepts of weak sustainability and strong sustainability operatively defined in the previous section.

Examples of weak sustainability indicators are environmentally adjusted national accounts and the net savings approach (well known as the Pearce-Atkinson measure and genuine savings). In strong sustainability indicators, the ecological carrying capacity and the resilience are presented. More examples of strong sustainability indicators can be given to the ecological approach based on criteria such as the safe minimum standard approach. The process of specifying and quantifying these indicators certainly evokes several concerns. This section also explores the commonly characterized concerns of weak and strong sustainability indicators.

2.3.2 Weak Sustainability Indicators

Weak sustainability indicators, environmentally adjusted national accounts and the net savings approach are characterized as indicators measured in monetary units. Monetary indicators identify the inefficient use of natural capital assets caused by market failure and internalize the social costs in the national accounting framework (Rennings and Wiggering 1997). Hence, weak sustainability indicators focus on getting prices right and correctly estimating the Hicksian notion of income which is the maximum consumption in the present period without reducing future consumption possibilities.

Another common feature of weak sustainability indicators is an empirical application of Hartwick's rule (Hanley et al. 1999). This approach assumes a high degree of substitutability between man-made capital and natural capital. This means that the costs of environmental depletion and degradation due to economic activities can be compensated by investment in man-made capital. This guarantees non-declining levels in the economy's sustainable income over time – assuming that the substitutability assumptions are valid.

2.3.2.1 Environmentally Adjusted National Accounts

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[14] According to some scientists, out of a possible 5 to 10 million species on Earth, only 1.4 million have been identified (Pearce and Atkinson 1995). However, there is a wide range of estimates for the total number of species presented by scientists (Pearce and Warford 1993).

Solow (1986, 1990), Hartwick (1990), and Mäler (1991) define the (environmentally) adjusted NNP as the best welfare measure of the stock and flows of natural and environmental resources. The message is "GNP incorporates priced resource input flows and these flows from capital stocks should be 'off-set' by deductions from GNP to incorporate declines (or possibly increases) in natural resource stocks. There is explicit 'economic depreciation' of natural resource capital which should be deducted from GNP to arrive at a correct estimation of NNP" (Hartwick 1990 p.291).

The approach is to calculate 'true' net national product, which is traditional GNP less the value of depreciation on man-made capital and environmental goods and services (marketed and non-marketed) used in economic activity.[15] This economic depreciation (of natural capital) is evaluated based on Hotelling rent (the difference between price and marginal cost) multiplied by change in the size of the capital stock in a given year.[16] Hartwick (1990) derives a formula for adjusted NNP:

$$\text{Adjusted NNP} = C + \dot{K}_m + (P_e - MC_e)\,\dot{K}_e + (P_r - MC_r)\,\dot{K}_r + (P_x - MC_x)\,\dot{X} \qquad (2)$$

where C = aggregated consumption; $\dot{K}_m$ = change in man-made capital stock; $\dot{K}_e$ = change in exhaustible natural capital stock (= $D_e - Q_e$; Q_e = extraction; and D_e = discoveries); P_e = price of exhaustible natural capital; MC_e = marginal cost of extraction of exhaustible natural capital; $\dot{K}_r$ = change in renewable natural capital stock (= $G_r - Q_r$; G_r = growth; and Q_r = harvest); P_r = price of renewable natural capital; MC_r = marginal cost of harvest of renewable natural capital; $\dot{X}$ = change in the volume of pollution; P_x = price of extra pollution that will be negative in a steady state; and MC_x = marginal cost of pollution abatement.

The adjustments are for changes in exhaustible and renewable resource stocks and for changes in the pollution volume. The signs on the adjustments are different in each case. For example, for renewable resources, since change in the stock of renewable resources is negative (harvest > growth), and the rent is positive, this leads to a downward adjustment in NNP. However, for pollution, increases in the volume of pollution ($\dot{X}$) have (P – MC) < 0 since P for a

[15] As the example of environmental capital (non-marketed), Hartwick (1990) deals with air pollution. This idea leads to the measure to reflect environmental quality as a kind of capital which is depreciated by the pollution and invested in by abatement.
[16] According to Solow (1992), there are two difficulties: 1) observed market prices have to be corrected for the worst of the distortions, i.e. getting the right price; and 2) the proper measurement of resource rents requires the use of numerical approximation to the marginal cost of extraction.

capital "bad" like pollution stock will be negative in a steady state (Hartwick 1991). The pollution abatement is then positive, so that increases in the stock of pollution lead to a decrease in NNP (Serôa da Motta 1994). Abatement cost is considered as part of income that cannot be considered as consumption and, therefore, must be deducted from the gross income for adjustment in NNP.

Note that, in formula *(2)*, the concern over natural resource management is implicitly included. Growth in renewable resources and discovery of exhaustible resources are taken into account ($\dot{K}_r$ and $\dot{K}_e$). If both stocks of renewable and exhaustible resources rise because of growth and discovery in the accounting period, then the value of this increase is added to NNP. Therefore, proper resource management can lead to increased (adjusted) income and economic welfare.

The sum of each depreciation value on renewable natural capital, exhaustible natural capital and pollution on the right hand side of *(2)* would be identified as the cost of environmental depletion and degradation. Adjusted NNP, then, can be regarded as a measure of sustainable national income. Hence, Hartwick's rule implies that an economy would sustain the constant per capita consumption paths over time with zero net investment (with increase in K_m just offsetting depreciation of natural capital):

$$\text{Adjusted NNP} = C \text{ iff } \dot{K}_m - \{(P_e - MC_e)\dot{K}_e + (P_r - MC_r)\dot{K}_r + (P_x - MC_x)\dot{X}\} = 0 \qquad (3)$$

If the overall stock of capital is depreciating, then the current level of consumption would exceed adjusted NNP. This means that the productive base or sustainable income is being eroded. On the other hand, if the overall stock of capital increases over time, then adjusted NNP shows upward trends, and the economy is following a sustainable path. In the latter case, it is assumed that the allowances made for capital consumption are reinvested in capital maintenance. In addition, the upward trends can be catalyzed by a variety of factors, such as technological progress, substitution of production factors, discoveries and growth of natural resources, or changes in consumption and production patterns (Bartelmus 1999).

2.3.2.2 Net Savings Approach

Pearce and Atkinson (1993, 1995) and Hamilton (1994) proposed a related measure of weak sustainability, the net savings approach, which is consistent with Hartwick's rule. This measure is also known as the Pearce-Atkinson Measure (PAM)[17] or genuine savings. Essentially, this measure tests more directly whether or not an economy is following Hartwick's rule. Therefore, if an economy or sector saves more than the combined depreciation on man-made capital and natural capital and then re-invests in these two forms of capital, then an economy might be thought as being on a sustainable path. This net savings measure is given as[18]:

$$Z = S - (\delta_m K_m + \delta_n K_n) \qquad (4)$$

where Z = net savings indicator; S = gross saving; δ_m = estimated rate of depreciation on man-made capital; K_m = stock of man-made capital; δ_n = estimated rate of depreciation on natural capital; and K_n = stock of natural capital.

In this measure, there are no special conditions on the level of natural capital (K_n). K_n can be decreased as long as K_m is accompanied by adequate compensation in the form of investment. This follows from the high degree of substitutability assumption that K_n and K_m are regarded as interchangeable in production. Note that the net savings measure is essentially identical to the environmentally adjusted NNP measure since equation *(4)* can be easily derived from equation *(2)* which defines environmentally adjusted NNP.

The test of sustainability is that the value of Z should be either positive or at least zero for sustainability:

$$Z \geq 0 \text{ iff } S \geq (\delta_m K_m + \delta_n K_n) \qquad (5)$$

Alternatively, if dividing by income (Y), we have the sustainability saving rule:

$$Z \geq 0 \text{ iff } S/Y \geq (\delta_m K_m/Y) + (\delta_n K_n/Y) \qquad (6)$$

This saving rule is then expressed in ratio components. By using percentages, we can measure a deviation from borderline or marginal sustainability (Pearce and Atkinson 1993).

This rule could be also expressed as compensation to future generations from current generations in terms of saving. Sustained positive values of a sustainable indicator imply a surplus of saving over the requirement to keep overall capital intact. On the other hand, sustained negative saving would lead the economy to an unsustainable path and eventually to declining

[17] This name, the PAM, is originally from Pearson and Veeman (1999).

welfare.[19] Thus, the net savings measure provides a very clear policy implication toward sustainability. That is, sustainability could be achieved with the combined low depreciation on K_m and K_n and high rates of saving (or high rates of investment), given efficient levels of natural resource exploitation.

2.3.2.3 Problems with Weak Sustainability Indicators

Weak sustainability indicators provide much better monetary measures than the traditional national income measures alone. They more fully reflect the reality of environmental depletion and degradation resulting from economic activities. In this sense, weak sustainability indicators give us a first step in capturing the economic aspect of sustainable development. However, there are many possible problems related to weak sustainability indicators.

First, there are obvious difficulties in constructing the complete list of natural capital. A number of natural capital assets, in particular non-marketed environmental goods and services and ecosystem functions, such as biodiversity and waste sinks, remain outside of the scope of the natural accounting system. The depreciation values derived from only marketed goods and services cannot provide a true picture of the total value of natural capital in an economy, for example $\delta_n K_n$ in the net savings approach. This significantly understates the 'true' gain and loss in the social value and brings about an accuracy issue in measuring sustainability.

Second, there is no clear consensus regarding substitutability between man-made capital and natural capital. We simply do not know the degree of substitutability. Indeed, no estimations of the degree of substitutability exist to be able to endorse or contradict the assumption of a high substitutability between the two major forms of capital: man-made capital and aggregate natural capital. There is no doubt that estimating the elasticities of substitution between K_m and K_n presents many difficulties. As pointed out by Cabeza Gutés (1996), there are the problems of data availability and the choice of production function form that does not impose too many restrictions.

Third, the process to estimate economic depreciation includes taking the present value of the stream of the future expected economic rent and discounting this stream using an appropriate rate of interest. However, it is not clear what interest rate is appropriate. One crucial feature of the traditional economic growth framework is that discounting tends to be determined according to

[18] For simplicity, it is assumed that δ_h = the value of depreciation on human capital equals to zero. This implies that knowledge and skills are regarded as having no depreciation.
[19] Atkinson et al. (1997) shows that even if investment in man-made capital is greater or equal to the depreciation value of natural capital at a given point in time (that is, a weak sustainability criterion is met), there is no way to conclude that the economy is on a sustainable path. Consistent dissaving would lead to non-sustainability.

the preferences of the current generation and not future generations (Costanza and Daly 1987, Peskin 1991). In this framework, discounting is regarded as rational and optimizing behavior based on individual preferences for current over future consumption under perfect information circumstance. However, as Page (1977) and others have shown, it is quite possible that a society could choose an optimal allocation of capital that could bring the economy to a halt in the future. Humans have a tendency to respond to the short-run and local benefit incentives and pressures that they perceive most directly. This can easily lead into unsustainable situations in which too much is discounted (Costanza and Daly 1987).

Fourth, weak sustainability indicators are premised on the assumption that population and technology are constant, based on Hartwick's rule. In the traditional economic growth framework, it is assumed that those are determined outside the economic system as exogenous variables and are not explicitly assessed in weak sustainability. In effect, the possibility of technological change, which Weitzman (1976) and Mäler (1991) call "unanticipated" change, is an important factor to identify. It might affect the operative constraint in weak sustainability, non-declining overall stock of capital, and the way that sustainable income is calculated.[20] For example, if the capital stock will become more productive because of technological change, keeping capital stock intact would leave future generations with higher welfare than current generations in spite of the increasing population (Weitzman 1976, Pearce and Atkinson 1995). In this case, technological change allows declining total capital stock and negative net saving, while achieving the goal of sustainable development.

Finally, weak sustainability indicators have not been developed for an open economy. They do not take into account the production of environmental goods and services for consumption in other countries or regions through international trade. Hartwick (1995) and Hartwick and Olewiler (1998) have pointed out this problem and then made an attempt to put a two country model or an open economy model in the weak sustainability framework.

Clearly, it would be an impossible task to provide a measure of sustainability overcoming these problems. Combining all the problems with weak sustainability indicators poses both theoretical and empirical challenges that need to be addressed in future research. Recognizing the limitations caused by these problems, this thesis applies weak sustainability indicators, environmentally adjusted NNP and the net savings approach, to the measurement of sustainability in Canada's forestry sector without any modifications.

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[20] Unanticipated capital embodied technological change results in less consumption and more investment, because it will add to productive possibilities only at some time in the future after the necessary capital has been accumulated (Weitzman 1976).

2.3.3 Strong Sustainability Indicators

Strong sustainability indicators are measured in physical units. Ecological scientists (including ecological economists) believe that the full contribution of critical natural capital to the aggregate life support functions of ecosystems cannot be expressed in monetary units (Ehrlich and Ehrlich 1992). Therefore, physical indicators that were linked to biophysical limits of the ecosystem have been advanced. In physical indicators, the spatial scale is an issue. The physical stocks and flows of natural capital assets are clearly constrained by the sizes and levels (or units) of spatial, temporal, or quantitative dimensions used to measure them.

Economists are interested in questions of efficient allocation determined by the price mechanism. If we get prices right for scarce natural capital and efficiently allocate it, then we do not have to think of the scale problem (Daly 1992). On the other hand, ecologists focus on environmental issues beyond mere allocation questions and try to find a sustainable scale. There seem to be different perceptions for the capacity of environmental resources and sinks between ecologists and economists. That is, economists assume that the total system is infinite relative to the scale of the economic subsystem. On the other hand, ecologists understand that the economic subsystem is strictly restricted by biophysical limits of the total system.

Another important feature of strong sustainability indicators is that man-made and natural capital are complementary rather than substitutable. Among the particular components of natural capital, substitutability for the life support functions is strongly denied. Strong sustainability indicators also share the argument of a finite ecosystem derived from the laws of thermodynamics and the need for prudence of irreverisbilities and uncertainties. In the following section, two important strong sustainability indicators are briefly outlined: the ecological carrying capacity and the resilience of ecosystems.

2.3.3.1 Carrying Capacity

Ever since the publication of an essay on *the Principle of Population* by Thomas Malthus in 1798, "there have been concerns that the human population is in danger of growing beyond carrying capacity of the earth" (Rapport 2000 p.367). The notion of carrying capacity is defined by biologist J. Roughgarden as "the maximum population size of a given species that an area can support without reducing its ability to support the same species in the future at a given level of technology within social organization, including patterns of consumption and trade" (Ehrlich 1994 p.42).

If we apply this concept to the human population, then human carrying capacity is interpreted as the maximum human population that consumes resources and discharges wastes indefinitely in a given area without damaging the functional integrity and productivity of the ecosystem (Rees and Wackernagel 1994). In short, this provides biophysical limits derived from not only the level of human population but also the level of economic activity under the current level of technology. However, in moving to the sustainability indicator of carrying capacity we need a more detailed specification of biophysical limits to work as an operational constraint of sustainability. The underlying constraint here is that if the limits are exceeded using current technologies, then economic activity is unsustainable, since human welfare is decreased by environmental depletion and degradation.

In the carrying capacity framework, an indicator that shows the degree to which biophysical limits have been approached or exceeded is the net primary productivity, as set out by Vitousek et al. (1986). The net primary productivity is a measure of the total amount of organic materials and lands annually used by humans directly or indirectly within a biologically fixed total system. Vitousek made an attempt to link the net primary productivity to the human carrying capacity at the global scale and calculated the world ratio (i.e. net primary productivity/human carrying capacity) under a variety of scenarios (Hanley et al. 1999). The ratio implies the magnitude of human 'appropriation' to the global net primary productivity every year (Vitousek et al. 1987). The conclusion of Vitousek et al. was that with current patterns of exploitation, distribution, and consumption, predicted increases in world population could not be supported. The net primary productivity measure at a national scale can be interpreted as showing how close to or far from its carrying capacity that the country holds. If the ratio is equal to 1, then the country's population is at a sustainable level, given the current organic material consumption.

A recent movement that is related to the carrying capacity concept is the ecological footprint, which purports to be an indicator of biophysical limits (Rees and Wackernagel 1994, Wackernagel and Rees 1997). Ecological footprints for a particular population is defined as "the area of productive land water ecosystems to produce the resources that the population consumes and assimilate the wastes that the population produces, wherever on Earth the land and water is located", using current technologies (Rees 2000 p.371). As seen from this definition, the ecological footprints are a land-based measure and are slightly different from carrying capacity (or the net primary productivity) that is typically defined as the population size that can be supported sustainably by a given area.

Ecological footprints essentially compare human per capita consumption for energy, food, and timber with available productive terrestrial land areas necessary to satisfy these demands in country *i*. As well, country's ecological footprint on the world can be calculated.[21] If country *i*'s ecological footprint is bigger than the land area (that is, a positive ecological footprint), then the country *i* exceeds biophysical limits and depletes country's natural capital or imposes part of ecological deficits on other countries via international trade (Hanley et al. 1999, Costanza 2000).

For example, according to estimates by Rees and Wicernagel (1994) and Rees (1999), the ecological support for human population in the geographical unit of the city of Vancouver, Canada, which is contained in an area of 11,420 ha, draws upon the productive land area of 2.36 million ha. Thus, the ecological footprint of Vancouver becomes 207 times the area occupied by its citizens. For the Lower Fraser Basin as a whole (the ecological unit in which Vancouver is located), the land area is 830,000 ha, while the ecological footprint to support the region's people is estimated to be 10 million ha. Therefore, the regional population imports the productive capacity of at least 12 times as much land to support its consumer lifestyles as it actually occupies.

The ecological footprint has also been calculated on a nation-wide basis.[22] Canada and Australia are among the few industrial countries that consume less than their ecological flows because of their sparse population and their large ecologically productive land areas (Wackernagel and Rees 1997). That is, Canada and Australia do not run ecological deficits. However, according to the ecological footprint concept, their natural capital stocks are depleted and degraded by the exports of primary products to support ecological footprints of people in other high per capita consumption industrialized countries such as Japan and the European countries.

There are several advantages of these indicators based on the concept of carrying capacity (Costanza 2000, Moffatt 2000, Rees 2000).[23] The major advantage is to give a clear message about biophysical limits and sustainability using a single number for both policy makers and the general public. Second, the calculation upon which both indicators are based on is relatively easy to measure and much of the data is available at different spatial scale.

However, economists have been much skeptical of the concept of carrying capacity and ecological footprints and question the relevance of these concepts to sustainable development policy (van den Bergh and Verbruggen 1999, Ayres 2000, Moffatt 2000, van Kooten and Bulte 2000). For example, van Kooten and Bulte (2000) suggested that these concepts are void of policy prescriptions other than more land, reducing population, or limiting consumption, which are

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[21] The ecological footprints do not account for aquatic areas such as lakes and oceans as ecologically productive areas.
[22] Wackernagel and Silverstein (2000) states that national boundary is the relevant unit for the question of sustainability.

to a great extent unrealistic and politically unacceptable suggestions. Carrying capacity, in particular ecological footprints, simply ignore the continuously evolving forces of technological change and institutional changes that might increase biophysical limits and the size of carrying capacity.

There is also an unjustified implication derived from the ecological footprints that no country should have an ecological footprint deficit (van den Bergh and Verbruggen 1999). This view suggests that trade is ecologically undesirable and self-sufficiency is a necessary condition of sustainability (Ayres 2000, Wackernagel and Silverstein 2000). However, as van den Bergh and Verbruggen (1999) point out, trade makes it possible for ecological footprint deficit areas to increase their carrying capacity by exchanging one kind of ecological service for another, which can increase the welfare of all involved in trade. It is very difficult to imagine that a country can be autarkic in ecological or economic terms, in the current world.

2.3.3.2 Ecological Resilience

Ecological resilience is the ability of a system to absorb disturbances without the system undergoing catastrophic changes (Holling 1973, Jansson and Jansson 1994, Arrow et al. 1995, Gibson et al. 2000). Uuder the assumption that all catastrophic changes are load, the sustainability constraint is that a system is unsustainable unless a system is capable of responding to stress or shock imposed by its environment, including economic activity.[24]

Of course, ecological resilience is not something that can be observed directly. This makes it difficult to establish a practical sustainability indicator to measure the degree of resilience. Hence, the search for a sustainability indicator based on the ecological resilience concept leads in the direction of measuring biodiversity, defined as a wide portfolio of natural (biological) capital, that are thought to be positively correlated with resilience (Common and Perrings 1992, Pearce and Atkinson 1996, Rapport 2000). Perrings (1994) insists that: "There is a direct link between resilience and biodiversity. Resilience is an increasing function of the size and complexity of ecosystems, where complexity refers both to the number of constituent populations in a system and to the interdependence between them" (p.102).

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[23] Moffatt (2000) mentions advantages (and limitations) associated with only the ecological footprint concept. However, some of them are capable of sharing with the net primary productivity measure.
[24] Stress is a small and predictable change, but can have large cumulative effects in an ecosystem. On the other hand, shock is a relatively large, temporary and unpredictable event. For a discussion of these topics see Conway and Barbier (1990).

This is reflected in arguments that the loss of resilience is frequently associated with declining biological productivity and also a quantitative reduction in ecological goods and services (Rapport 2000). According to Pearce and Atkinson (1996), if we restrict ourselves to an agricultural system, an example of an indicator is an output-based approach that measures the variability in crop yields. Upward trends in production are believed to be associated with increasing variability of yields in a given year. A measure of this variability is the coefficient of variation. Hence, the resilience indicator might be expressed as changes in the coefficient of variation of crop productivity over time.

Common and Perrings (1994) have attempted to establish keystone functions and keystone species in environmental goods and services as a resilience indicator. The loss of resilience in a system occurs when a set of critical thresholds of these keystone species is crosses. Therefore, the protection of some upper bounds on the assimilative capacity to sink wastes and lower bounds on the level of species stocks is a necessary condition of sustainability (Turner et al. 1994). For example, ecologists assume that the presence of grizzly bears is an ecological resilience indicator of ecosystems.[25] Grizzly bears require large and disturbed areas to survive. They take a long time to mature sexually, and an average female produces just four or five cubs to the population in a 20-year breeding period. Hence, grizzly bears are believed to be vulnerable to changes in the ecosystem.

This approach suggests establishing the safe minimum standard (SMS) (Ciriacy-Wantrup 1952, 1968, Bishop 1978) and the precautionary principles (Costanza et al. 1994, Francis 1996) for preserving critical natural capital components and the life support functions of the ecosystem in the presence of inevitable uncertainties and irreversibilities of ecological complexities (Ehrlich 1994).[26] In particular, the precautionary principle strongly recommends that decision-makers act in advance of scientific certainty to safeguard the critical natural capital stock in physical terms against the potentially harmful effects of some decisions (O'Riordan and Jordan 1995). In other words, the precautionary principle provides decision-makers with very flexible risk-averse strategies reflecting the ethical judgement without adequate accumulation of scientific knowledge and information or detailed risk assessment.

Pearce and Atkinson (1996) argue that the ecological resilience indicator might have more appeal than the carrying capacity indicators as the strong sustainability indicator. This is because

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[25] See articles written by E. Struzik in the Edmonton Journal, A7 on April 18, 2000 and E8 and E9 on May 21, 2000.

[26] While a close cousin to the SMS criterion, the precautionary principle is not the same. According to Turner et al. (1994), "the precautionary principle goes beyond the SMS in that any losses to 'critical' natural capital and significant losses to 'other' natural capital are unacceptable" (p.271). The SMS's strategic consequence based on the cost-benefit analysis states that critical natural component should be conserved unless the social opportunity costs are unacceptably large. On the other hand, the precautionary principle says, whatever the benefits forgone, some critical natural capital (e.g. keystone species) for which substitution is impossible or very difficult must be conserved.

measurement of the level of biodiversity in ecosystems is more emphasized in the indicator. This non-declining diversity from current levels has a direct link with the operational definition of strong sustainability, non-declining stocks of natural capital assets over time.

2.3.3.3 Problems with Strong Sustainability Indicators

The concept of strong sustainability brings important ecological constraints on the issue of sustainable development, such as biophysical limits in carrying capacity and ecological resilience. These are likely to be easily understood and acceptable ideas to decision-makers and the general public. However, the practical application of strong sustainability concepts and implications raises various conceptual problems.

First, no clear or measurable levels of natural capital components, nor the components themselves, have been identifies that would give a clear operational definitions of sustainability. For example, to operationalize strong sustainability, hundreds, thousands, or more keystone functions and keystone species might be required in the ecological resilience indicator. In addition, there is obviously a lack of consensus on what keystone functions and species should be included and what the critical levels or thresholds of these should be.

Identification of ecologically critical components and levels requires information of the ecosystem conditions on which to base an assessment. The relevance of components and levels can only be identified by scientific understandings and consensus (Ludwig et al. 1993). Therefore, a large set of data rigorously and objectively gathered by ecologists must be a prerequisite for providing indications of ecological criticality. However, it is difficult for ecologists to keep objectivity in the scientific process. Partly, this is because ecologists are increasingly involved in emotionally charged environmental debates (Weins 1997).[27] They have been exposed to the social pressures from particular interest groups sharing common business, cultural, religious, or political agendas in the debates.[28] The larger and the more immediate prospects for gain are, the greater the pressures that are used to facilitate exploitation of natural capital (Ludwig et al. 1993).

The lack of objectivity, for example, might lead to bias in the selection of study area (Weins 1997). In addition, even if a study is objectively designed and analyzed, the findings must be interpreted in a context that a particular pressure group finds favorable. This prevents formation of clear scientific consensus to identify and determine ecologically critical components and levels

[27] According to an ecologist J.A. Weins (1997), "we care about the environment; that is why many of us became ecologists in the first place. Faced with the uncertainty that characterizes most feeling in ecological research, it is all too easy for these feelings to influence how we view data, which results we choose to emphasize or to disregard, or whether what begins as speculation transformed into fact" (p.3).
[28] These pressures are often associated with opportunities for research funding (Weins 1997).

in the face of scientific uncertainty in ecosystems. Consequently, it is difficult to determine ecological criticality based on only scientific consensus. Rather determination of ecological criticality might depend on all anthropocentric factors such as the standard of living and relative affluence of a particular interest group, or more broad economic, social, and political factors (Pearce and Turner 1990, MacDonald et al. 1999).

Some attempts to establish strong sustainability criteria have been made. A comprehensive definition of critical natural capital are ecological assets that are 'essential' to human health and the functioning of life support systems (Pearce and Turner 1990). These would also be characterized as unsubstitutable or irreversible for environmental changes.[29] However, literatures contain few suggestions on an appropriate disaggregation of the unique or multiple ecological services. In other words, there is no guidance as to what degree of aggregation of natural capital is 'essential' to human well-being or survival (MacDonald et al. 1999). Thus, the degree of aggregation is a second difficulty with strong sustainability indicators. For example, imagine the difficulty of reaching social consensus for maintaining the qualitative and quantitative levels of broad classes of natural capital, such as air, soil, water, forest, and biodiversity. Reaching consensus for preserving specific wildlife habitats and species of plants and animals would be perhaps more difficult.

Third, the strong sustainability indicators are measured in physical units. However, adopting a physical indicator has some problems. First, it is impossible to obtain an objective measure of the importance of ecological services relative to ordinary marketed goods and services (Peskin 1991). Second, since there is a more practical problem of measuring in physical units, it is not clear what units should be used as common numeraire to compare different categories of natural capital in a common format (Bartelmus 1999). No single physical unit of measurement seems appropriate for all of them. For example, physical accounts would not be adequate to distinguish important differences in composition, quality, age-class structure, and above all value of timber resources. While they give us a mountain of statistics in the form of disaggregated details related to Canada's timber stock, they are not easily summarized or processed.

The one of the advantage of using monetary units as a numeraire is revealed by arbitrary weighting among environmental functions and natural capital components used in some strong sustainability indicators. For example, in the ecological footprints literature, the fact that energy accounts for over 50 per cent of the footprint for most developed countries has been emphasized

[29] Little is empirically known about environmental assets for which few or no substitutes exist. In addition, the strong sustainability indicators, in particular carrying capacity, are extremely pessimistic regarding the role of technological change (Pearce and Atkinson 1996). However, as pointed out by Moffatt (2000), carrying capacity could be substantially expanded using environmentally friendly technologies, using current technologies more efficiently, or reducing the throughout of resources.

(van den Bergh and Verbruggen 1999). In some cases, aggregated weights are derived from ecological knowledge. But this does not correspond at all to the long-term technological potential or current 'social' weights for inputs (i.e. market prices) (Ayres 2000). These weight-factors "reflect neither relative scarcity changes over time nor variation over space...." (van den Bergh and Verbruggen 1999 p.64) and a fixed rate of substitution is supposed between different categories of environmental pressure. Worse still, some categories receive identical weight, even when it is clear that their environmental impacts are very distinct.

Fourth, strong sustainability indicators do not generally address the complex spatial and temporal links between a study area and surrounding ecosystems or interactions across scales. Even if ecological scientists have long understood the importance of the concept of scale, most generally focus on one scale at a time, and the problem of relating phenomena on different scales is rarely addressed (Levin 1997, Weins 1997, Gibson et al. 2000). Therefore, strong sustainability indicators are essentially regarded as a static measure (Pearce and Atkinson 1996, van den Bergh and Verbruggen 1999, Deutsch et al. 2000, Moffatt 2000). The available data are usually constrained to a single point in time (van Kooten and Bulte 2000). It makes it difficult to provide the relevant information to measure sustainability over time, that is, changes of biophysical limits that ecological carrying capacity might be or changes in biodiversity that ecological resilience might be positively correlated with. For example, in a criticism of the use of net primary productivity as an indicator, Vitousek et al. (1997) states that: "The information presented here (the calculation of the net primary productivity) cannot be used directly to calculate the Earth's long-term carrying capacity for human beings because carrying capacity depends on both the affluence of the population being supported and the technologies supporting it" (p372).

Scale presents a difficult challenge in attempts to generalize findings because results are usually obtained from studies at a particular scale. Scaling-up is a matter of applying findings from the analysis of a small scale or microlevel system to a larger scale or macrolevel system. Scaling-down is the inverse operation. However, ecosystems are normally characterized as complex, non-linear, discontinuous adaptive systems that are far from any stable equilibrium (Levin 1998, Gibson et al. 2000). As well, economic activity has different levels of influence and impact on ecosystems with interactions between different scales. In these conditions, simple predictions and generalization from one scale to different scales are probably not valued. As pointed out by Deutsch et al. (2000), " For communication purpose, we express the work of nature as an area, but we do not reduce its complexity to a single dimension to be used as an operational indicator of ecological carrying capacity, sustainability or as a basis for a discussion on equity" (p.352).

In addition, there is no clear guidance how sustainability findings should be extrapolated to different scales. Ecologists typically try to understand the relations at one scale level of ecosystem as an aggregation of interactions among smaller-scale level units (Gibson et al. 2000). However, unless one makes very strong and unrealistic assumptions about each lower-level unit, the aggregate findings may not correspond with findings at a smaller level. For example, Levin (1997) states that "efforts to predict responses of forests and grasslands to global change ultimately depend on understanding how individual plants respond to changing environments, but we do not understand well enough how to scale up from such information to the responses of ecosystems" (p.1).

Another scale issue surrounding scale is substitutability of critical natural capital components across regional boundaries. For example, wildlife species of plants and animal that are threatened or extinct in one region may naturally migrate across regional boundaries, undermining local preservation attempts. Furthermore, it might be possible to transfer some species from areas where they are not threatened or extinct to those where they are threatened or extinct or from regions of relative abundance to those of relative scarcity, as having been done with timber wolves in Yellowstone National Park.[30]

Implementing strong sustainability criterion turns to be very difficult as conflicting objectives are sure to arise. If no social consensus exists on what kind of natural capital to preserve, society may be unwilling to accept the opportunity costs of restricting the enhancement of their economic welfare. Hence, MacDonald et al. (1999) state that "At the level of implementation there would need to be radical change in the institutional and legal framework that would challenge the current thinking which tends towards balance, compromise, and consensus" (p.85).

The safe minimum standard (SMS) approach is an alternative criterion that attempts to deal with complexities and uncertainties inherent in ecological systems.[31] The SMS approach uses the minimax regret criterion as the decision rule for preservation of natural capital. That is, decision-makers acting on behalf of society should choose a cautious rule that minimizes maximum possible future losses in the observed prevalence of risk aversion (Palmini 1999). Advocates of such conscious rules (such the SMS) suggest that these approaches should be taken unless the opportunity costs of conservation are unacceptably large (Bishop 1978).

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[30] CITES, the Convention on International Trade in Endangered Species of Wild Fauna and Flora, are not banning the transit or transshipment of endangered wildlife species of animals and plants through or in the territory of the State. CITES is an international treaty to protect wildlife species against such over-exploitation and to prevent international trade from threatening species with extinction. It entered into force on 1 July 1975. Canada ratified CITES treaty on 4 October 1975. See http://www.wcmc.org.uk/CITES/index.shtml

[31] The SMS approach originated with Ciriacy-Wantrap (1952, 1968). The basic notion was developed by Krutilla (1967) who applied the concept to unique components of natural environments, and was reinforced by Bishop (1978) with the provision of the SMS approach as a decision-making rule in preservation/development decisions.

However, this alternative approach does not overcome the difficulties of determining the relevant scales or levels and the issue of how 'unacceptably large' should be defined. While this approach relies to some extent on aggregate public preference or social consensus, public tastes might change across spatial and temporal scales. Even if members of one society in a given time are aware of some ecologically critical components and levels and decide to preserve natural capital components, members who live in the same society in some future periods or live in other societies in same period time might have different perceptions. In particular, when the latter members do not share direct or indirect benefits for maintaining the stock levels of the natural capital components, this issue will be more complicated. Thus, this approach remains open to subjective interpretation.

In the absence of a clear guidance on ecological criticality, degree of aggregation, scientific and social consensus on ecological criticality, and the determination of spatial and temporal scale levels, strong sustainability indicators are likely to be perceived as arbitrary. Solving all these problems presents an unrealistic demand. If these issues prevent strong sustainability indicators from being usable by decision-makers and, to some degree, understandable to the general public, those measures are of little or no value (Ehrlich 1994, Weins 1997). Indeed, strong sustainability indicators offer no concrete policy suggestions apart from, in ecological resilience, conserving the physical levels of the critical natural capital stock and, in ecological footprints, including more productive land, reducing population, or reducing consumption per head in ecological footprints. The policy instruments required to achieve such desirable criterion are not stated. Given the failure of the strong sustainability indicators to assess in physical terms, the alternative is indeed to use the rigorous and robust tools of monetary valuation (Bartelmus 1999).

On the other hand, information gathered in rigorous and unbiased ways by ecologists would be a prerequisite for monetary indicators. Thus, researchers have to avoid losing their objectivity in analysis by involving emotionally charged environmental debates. As stated by Weins (1997), "there is the paramount responsibility to distinguish clearly between statements that are based on science and those that are based on personal values or viewpoints. As ecologists, our agenda should be science, and our responsibility is to ensure that scientific findings carry the greatest possible weight in societal decisions about the environment" (p.3).

Chapter 3 Sustainability of Canada's Forest Sector

3.1 Introduction

This chapter will investigate sustainability of Canada's forest sector for 1970-93 using weak sustainability indicators developed in chapter 2. Two main methods are used to estimate economic depreciation of Canada's timber resources: the net price approach and the adjusted approach suggested by Vincent and Hartwick (1997) for accounting for the age-class-distribution in forests. The estimates of economic depreciation are limited to wood removed from the forests for manufacturing timber products in Canada's forest sector. Because of data limitations, no attempt will be made to correct for estimation associated with non-timber goods and services.

The chapter will be organized as follows. First, forest sector resource accounts are defined in a natural resource accounting framework. Second, physical accounts of Canada's timber resources are discussed. Third, methods used to calculate economic depreciation: the total timber rent calculation, the net price approach, the net price approach with growth stock effect, and the Vincent-Hartwick approach are outlined and the empirical results of Canada's timber resources from 1970 to 1993 are presented. Finally, Canada's forest sector's sustainability is measured using weak sustainability indicators.

3.2 Forest Sector Resource Accounts and Timber Resource Accounts

Environmentally adjusted forest sector resource accounts have the same framework as environmentally adjusted national accounts. Adjusted forest sector NDP is defined as:

Adjusted forest sector NDP = conventional forest sector GDP + consumption of non-timber goods and services – depreciation of man-made capital depreciation of timber stock – depreciation of non-timber goods and services

This adjusted measure includes the terms of consumption of non-timber goods and services and the depreciation values. Forests provide society not only with timber products but also with a number of non-timber goods and services [32]

[32] See details about the explanations of non-timber goods and services in Haener (1998).

Non-timber goods and services might represent a significant portion of Canada's forest resource accounts. Indeed, there is a certain consensus that these values should be fully reflected in forest resource accounts. While there are some attempts to estimate non-marketed assets and incorporate them into natural resource accounts at the national level, including Mexico (Adger et al. 1995), Sweden (Hultktantz 1992), and Papua New Guinea (Bartelumus et al. 1993, 1994), the methodology and statistical data used in the estimation have been a controversial subject.

In Canada, there has not yet been an estimation of non-timber goods and services at national level. There are a number of case studies limited to specific local regions, wildlife species in specific habitats, and non-timber user services, including northern Alberta (Haener 1998), woodland caribou in northwestern Saskatchewan (Tanguay 1994), and recreational activity in Alberta (Balasubramaniam 1992). However, as seen in previous works, we cannot derive the whole of Canada's estimations of non-timber goods and services from piecemeal case studies. There is no evidence to support the idea that the unit willingness-to-pay derived from CVM for people's preferences explored in experimental studies of selected non-timber goods and services or particular local region would be the same across spatial and temporal scale levels in Canada. For example, one local preference in a wildlife habitat may differ substantially from the preferences of the general public who live in different regions. These value differences depending on scales in some instances have been the root of environmental conflicts (Adamowicz and Veeman 1998).

In this analysis, given the difficulty of estimating values associated with non-timber goods and services at the national level, we will focus on the economic depreciation values only to wood removed from the forests for manufacturing timber products in Canada's forest sector. The forest sector includes the logging industry, the wood industries (e.g. lumber, plywood, and panelboard manufactures) and the paper and allied industries (e.g. pulp mills, newsprint mills, and producers of fine paper and paperboard products). The framework is defined as:

Adjusted forest sector NDP = conventional forest sector GDP – depreciation of man-made capital in forest sector – depreciation of timber stock in forest sector

The timber resource accounts excludes the terms of non-timber goods and services in the right-hand side of the forest resource accounts framework. In this framework, substantial non-timber products and services remain outside the scope of this study, as in the like conventional national accounts. Thus, this clearly understates the true gain and loss in social value associated with forest resource assets.

The adjusted forest sector NDP provides the framework for the calculation of economic depreciation in section 3.3 and for the measurement of weak sustainability in Canada's forest sector in section 3.4. A necessary first step in this calculation is construction of physical resource accounts which is done in the next section.

3.3 Timber Resource Accounts for Canada's Forest Sector from 1970 to 1993

3.3.1 Physical Timber Accounts

This section describes Canada's physical timber accounts. As suggested by Repetto et al. (1989), physical accounts for timber resources could be expressed in both volume (cubic meters) and area (hectares) of available wood. In physical accounts, appreciation/depreciation of timber stocks is equivalent to the net increase/decrease in total standing timber volume or timber productive forestland area from the national forest inventory in a given period (Liu 1998). Change of timber stock is generally calculated using a combination of data sources and timber growth simulation models. Statistics Canada (1997) developed a simulation model that represents eight provinces and one territory[33], three forest types (softwood, mixedwood, and hardwood)[34], and nine 20-year age class based on Canada's Forest Inventory 1991 (CanFI91) (Statistics Canada 1997).

CanFI91 has been developed as "the authoritative national statement on the distribution and structure of the forest resource" by the Canadian Forest Service of Natural Resources Canada (Lowe, Power, and Gray 1994 p.4). This is complied from forest inventory data for national area and volume summaries on topics such as ownership, status, productivity, site quality, stocking, disturbance, age, forest types, and species groups, provided by the provincial and territorial forest inventory agencies through the Canadian Forest Inventory Committee (CFIC). This national inventory has been revised every five years (i.e. 1981, 1986, 1991) using the most current data available from provincial, territorial, and federal responsible agencies.[35] They know of recent major regional disturbances (e.g. extraordinary fire losses) or administrative changes (e.g. the assignment of new forest management agreements or the designation of large protected areas) and input those new factors in the data.

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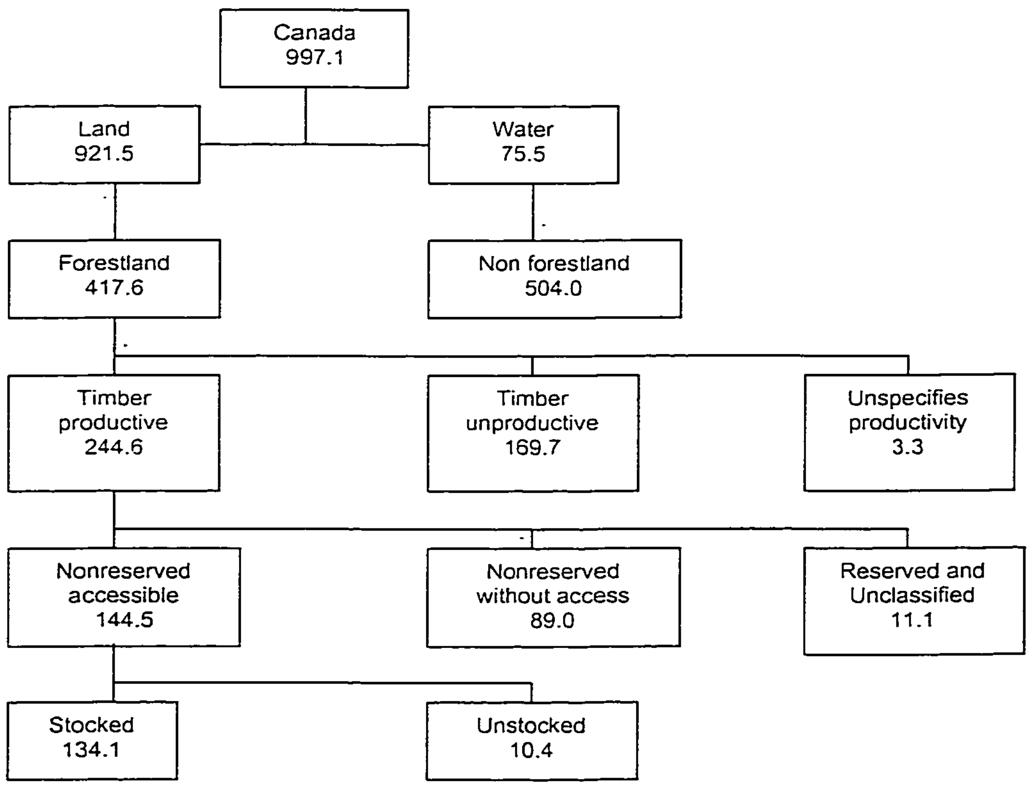
[33] It excludes Price Edward Island, Manitoba, and the Northwest Territories since their age-class distribution data are not available (Statistics Canada 1997).
[34] Canada's timber productive forests account for 62 per cent of softwood, 16 per cent of hardwood, and 18 per cent of mixwoods. As another aspect of forest composition, coniferous species such as Spruce, Pine, and Fir accounts for 77 per cent of timber productive forests and broadleaved for 23 per cent (Lowe, Power, and Gray 1994).
[35] CanFI91 was updated in 1994 to include new data for Quebec since Quebec had not supplied current data for Canada's Forest Inventory 1986 and 1991 (Lowe, Power, and Gray1996).

According to the inventory area classification by CanFI91 (Figure 3.1), 244.6 millions of hectares (59 per cent) of Canada's total forestlands (417.6 millions of hectares) is designated as "timber productive forest" and 169.7 millions of hectares (41 per cent) as "timber unproductive". Timber productive forestland is defined as better growing site capable of producing a merchantable crop within a reasonable length of time (Statistics Canada 1997). This classification is based on site quality, regardless of the extent of timber use or other use of the forest. However, some of this area is considered inaccessible and reserved for the purpose of protecting wildlife species of plants and animals. On the other hand, some unproductive forestland might be quite productive for wildlife (Lowe, Power, and Gray 1994). In this chapter, we are considering timber only. Hence, only "timber productive forestland" is used in this analysis.



Notes: Area is measured by millions of Hectares.
Shaded areas represent data used in the physical timber account.
Source: Canada's Forest Inventory 1991 (Lowe, Power, and Gray 1994) and Statistics Canada (1997)

Figure 3.1 Area by Land Class and Stocking

Out of the timber productive forestland, currently, 144.5 million hectares (35 per cent of Canada's total forestland) are managed for potential timber production as nonreserved accessible forestland (144.5 millions of hectares), while the much of remaining "productive forest" has not been accessed or allocated for timber management. The nonreserved accessible stock is further subdivided into accessible nonreserved stocked (134.1 millions of hectares)[36] and nonstocked[37] (10.4 millions of hectares) timber productive forestland areas. These are the forestland classes used in the simulation model for the physical timber account (Statistics Canada 1997). This nonreserved accessible forestland implies that the land area is a source of physical timber supply. Hence, the term accessible refers to physical access to the timber resource and is not concerned with whether the resource is accessible commercially. This could be distinguished from the forestland that is only commercially operable forestlands, depending on such things as quality of timber, road or railway networks, labor availability, terrain and distance to mills (Forestry Canada 1991).

Although these inventories are conducted periodically and might present the best information available at the time, they are influenced by procedural differences in the practices (e.g. selection of different land base) and timing of the source inventories when they are included in the national inventory. If no new source inventory was produced for a given area between 1986 and 1991 then the 1986 data were used again. As stated by Lowe, Power, and Gray (1994), the numerical difference between the 1986 and 1991 inventories are not necessarily due to the real changes during the five-year period. Consequently, consistent stock data are not available as an annual time series.

To overcome the lack of consistency, Statistics Canada (1997) estimated the stock/flow time series of the physical timber account using a simulation model. Beginning with inventory data for a single year (1991), the model simulates the impact of fire, mortality, harvesting, ageing, and natural and artificial regeneration to timber stocks over the time period 1961-90.[38] As a first step in simulating the evolution of the forest, a 1961 age-class distribution is estimated by running a version of the model backwards. Using this estimated age-class distribution as the initial condition for 1961, the model is then run forward to meet the desired 1991 data points. A similar procedure was used to obtain the 1970-91 age-class distributions for estimating economic depreciation by the Vincent-Hartwick approach, as described in section 3.2.3.11 and Appendix II.

Changes of Canada's timber stock volume in the period 1970-93 are presented in Table 3.1 and Figure 3.2. The volume data from 1970 to 1990 is available using the simulation model by Statistics Canada (1997). However, data are not available during the period 1991-93. Therefore, the volume changes of harvest, roads, mortality, and regeneration for 1991-93 can be

[36] Defined as forestland supporting tree growth includes seedling and sapling (Statistics Canada 1997).
[37] Defined as forestland that lacks trees completely, that is so deficient in trees because of either young or old, or that is residual stand for merchantable tree species, if any, will be insufficient to allow utilization in an economic operation (Statistics Canada 1997).
[38] See the section 3.4 Timber Asset Accounts of Statistics Canada (1997) about the detailed model structure.

Table 3.1 Variations of Timber Stocks (Volume) (Canada)

(Thousands of cubic meters)

Year	Opening stock	Harvest	Mortality (a)	Fire damage	Roads	Regeneration (=CAI)	Net reduction	Closing stock
	1)	2)	3)	4)	5)	6)	7)=2)+3)+4)+5)-6)	8)=1)-7)
1970	14,538,759.4	120,120.0	45,498.2	23,703.2	3,603.6	152,382.3	40,542.7	14,498,216.7
1971	14,498,216.7	118,052.0	45,717.2	27,604.8	3,541.6	154,818.8	40,096.8	14,458,119.9
1972	14,458,119.9	122,261.0	45,940.8	12,131.5	3,667.8	156,729.9	27,271.2	14,430,848.7
1973	14,430,848.6	142,729.0	46,050.6	2,774.4	4,281.9	151,766.8	44,069.1	14,386,779.5
1974	14,386,779.7	135,778.0	46,076.2	19,704.1	4,073.3	157,139.2	48,492.4	14,338,287.3
1975	14,338,287.2	113,193.0	46,357.3	3,378.4	3,395.8	165,223.7	1,100.8	14,337,186.4
1976	14,337,186.5	137,345.0	46,463.2	17,963.6	4,120.4	160,795.8	45,096.4	14,292,090.1
1977	14,292,090.1	143,446.0	46,536.7	15,052.8	4,303.4	158,820.9	50,518.0	14,241,572.1
1978	14,241,572.1	154,034.0	46,566.4	3,666.2	4,621.0	157,971.9	50,915.7	14,190,656.4
1979	14,190,656.3	159,750.0	46,571.9	9,110.9	4,792.5	160,841.3	59,384.0	14,131,272.3
1980	14,131,272.3	152,908.0	46,516.2	49,742.0	4,587.2	156,698.4	97,055.0	14,034,217.3
1981	14,034,117.2	142,562.0	45,950.8	51,845.6	4,276.9	162,416.5	82,218.8	13,951,898.4
1982	13,951,989.5	125,347.0	45,480.0	50,499.1	3,760.4	167,182.3	57,904.2	13,894,085.3
1983	13,893,994.3	154,082.0	44,880.8	16,231.1	4,622.5	162,043.6	57,772.8	13,836,221.5
1984	13,836,221.6	165,726.0	44,291.4	5,659.8	4,971.8	163,034.3	57,614.7	13,778,606.9
1985	13,778,607.0	166,594.0	43,733.8	7,620.1	4,997.8	169,633.5	53,312.2	13,725,294.8
1986	13,725,294.8	175,063.0	43,133.2	13,276.2	5,251.9	168,812.4	67,911.9	13,657,382.9
1987	13,657,383.0	189,318.0	42,507.0	11,343.3	5,679.5	162,796.6	86,051.2	13,571,331.8
1988	13,571,331.8	188,018.7	41,889.9	14,518.8	5,640.6	165,128.9	84,939.1	13,486,392.7
1989	13,486,392.7	184,191.6	41,140.0	98,230.2	5,525.8	164,330.1	164,757.5	13,321,635.2
1990	13,321,635.3	157,449.2	40,746.9	13,264.4	4,723.5	170,352.6	45,831.4	13,275,803.9
1991	13,275,803.9	184,108.0	39,385.5	14,518.8	5,523.3	169,097.3	74,438.4	13,201,365.5
1992	13,201,365.5	187,217.5	37,937.2	14,518.8	5,616.6	169,799.1	75,491.0	13,125,874.6
1993	13,125,874.6	190,327.0	36,424.5	14,518.8	5,709.9	170,500.9	76,479.2	13,049,395.3

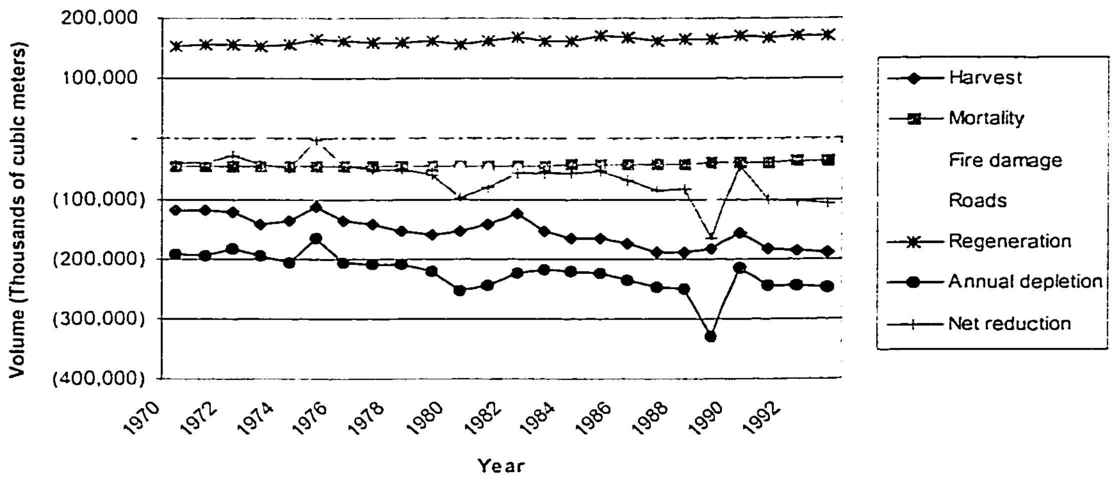
Notes: (a) Mortality of forest implies death or destruction of forest trees as a result of competition, disease, insect damage, draught, wind, and other factors, excluding harvest fire damage (Statistics Canada 1997).

Source: Statistics Canada, Econnections, 1997.

extrapolated based on the trend information of the time series from 1970 to 1990.[39] The volume changes of fire damage can be estimated using the median to avoid being affected by extreme values for 1970-90 and assumed to be constant for 1991-93.

In calculating changes in physical stocks, the basic identity is expressed that the volume at the end of a period (the closing stock) equals to the initial volume (the opening stock) plus growth (or increment) through natural and artificial regeneration, less harvest, losses because of logging roads and natural losses such as fire and insect damage. It is clear from Table 3.1 that the volume of timber stock has been declining over time mainly because of harvesting, mortality, and fire damage. As suggested earlier, physical accounts are only a step in the process of constructing sustainability indicators. In the next section, monetary timber accounts are discussed.

Figure 3.2 Valiations of Timber Stocks (Volume) (Canada): 1970-93



3.3.2 Monetary Timber Accounts

[39] The trend, linear or non-linear, can be measured by a regression method. In this case the time trend *t* can be defined 1, 2, 3, ..., from 1970. The estimates are:
Harvest = 3,109.5t + 115,699 (R-squared = 0.698)
Mortality = $-32.185t^2$ + 457.23t+ 44,904 (R-squared = 0.9863)
Roads = 93.286t + 3,471 (R-squared = 0.6983)
Regeneration = 701.83t + 153,657 (R-squared = 0.6561)
The fit is measured by the R-squared, which a value near to one indicates a close association between the dependent and independent variables, which are each physical volume and t respectively.

Monetary accounts of timber resources provide a common yardstick to measure the volume change of timber stock. The market value of timber resources is the price that would be paid for timber products if they were sold in a competitive public market. Under perfect market conditions, the monetary change in the value of timber resource stocks is equal to change in the present value of the sum of future expected profits due to harvesting, taking into consideration the side of natural losses such as fire and insect damages. The capital value of timber resources could be depreciated if the expected natural losses surpass timber stock growth in the same period.

However, measuring the market values of timber resources in Canada is problematic. Since 94 per cent of the Canada's forests is publicly owned by the federal and provincial governments[40], transactions in forestlands or cutting rights seldom happen. Therefore, the market values of timber resources have to be estimated using 'indirect' methods (Statistics Canada 1997). One of these is based on the concept of timber resource rent, in other words the estimated economic depreciation of timber resources. This concept is central to natural resource valuation in monetary terms (Repetto et al. 1989).

The estimated economic depreciation may be indirectly useful for influencing timber production and demand pattern. For example, timber demand and production may be influenced by resource use charges and these charges may in part be based on estimates of economic depreciation. As stated by Bartelmus (1994), the idea is to get the prices 'right', that is, to internalize fully all external or social costs accompanied with timber harvesting and natural losses from forestlands. Hence, timber resource accounts might work as an information system that imputes the level of externalities in a society, because this prevents allocation of a disproportionate share of current income flows to present generations at the expense of future generations.

There is actually no consensus on the correct methodology for estimating economic depreciation (Vincent and Hartwick 1997). However, as seen in most case studies, two methodologies: the net price approach and El Serafy's user cost approach seem to be standardized for valuing stocks of natural resources. In this thesis as well, the net price approach is central to the discussion of estimating economic depreciation of Canada's timber resources in

[40] 71 per cent of the forests are under provincial jurisdiction, 23 per cent are under federal jurisdiction, and the remaining 6 per cent are in the hands of an estimated 425,000 private landowners (Lowe, Power, and Gray 1994). Under constitutional powers over Canada's environment, the provincial governments hold most regulatory powers applicable to the natural environments. Under a 1982 amendment to the Constitution Act (section 92A), each province has exclusive jurisdiction over management of its provincially owned natural resources (Field and Olewiler 1995). On the other hand, the Constitution Act gives the federal government the power over interprovincial and international trade and the power to levy taxes and to make expenditures, as well as the First Nations and their reserved lands (e.g. national parks) (Field and Olewiler 1995). The federal government enacts environmental regulations based on 'national' concern for environmental protection and sustainable management objectives in the interests of "peace, order, and good government". However, as pointed out by Field and Olewiler (1995), the jurisdictional powers of the federal and provincial governments sometimes overlap and easily cause conflicts between the 'national' concern and the 'provincial' concerns.

the period 1970-93 in the following section.[41] On the other hand, El Serafy's user cost approach will not be applied to calculate the depreciation because of the characteristic depending on complicated forecast models to obtain a projection of future timber rents, in particular in the case of renewable resources sustained infinitely like Canada's timber resources. The net price approach is a simpler and more practical approach than El Serafy's user cost method.

3.3.3 Estimating Economic Depreciation of Canada's Timber Resources

This section is concerned with the calculation of economic depreciation of Canada's timber stocks and the calculation of sustainability indicators. The section is organized in 10 subsections. First, forest policy frameworks under which forest resources are managed are described in subsection 3.3.3.1. This provides context for the calculations which follow. Economic depreciation calculations proceed in two steps for each method (the net price approach and the Vincent-Hartwick (V-H) approach). First, the total timber rents are calculated in subsection 3.3.3.2. Results from the calculation are presented in subsection 3.3.3.3. The net price approach is then implemented in subsections 3.3.3.4 – 3.3.3.6. These estimates are compared in subsection 3.3.3.7. Regeneration costs are not incorporated into the net price approach. These costs are discussed in subsection 3.3.3.8. The V-H approach implemented in subsection 3.3.3.9 takes into account regeneration costs. Results from the V-H approach are described in subsection 3.3.3.10. The results from the net price approach and the V-H approach in section 3.3.3 are used as inputs in the calculation of weak sustainability indicators in section 3.4.

3.3.3.1 Forest Tenure Policy Framework

Estimation of economic depreciation for Canada's timber resources is complicated by Canada's forest management system. Canada's timber resources are harvested and managed by the private sector, while they are mainly owned and overseen by the provincial governments. The provincial policy frameworks set out the conditions for the private sector to operate on Crown lands. These are known as forest tenures (Luckert and Salkie 1998). The degrees of tenure arrangement vary according to the province. The size of tenure and the length of lease determine the conditions of renewal/replacement of tenure and responsibilities after harvesting. Most long-term leases now require tenure holders to regenerate the forestland, build roads, guard against fire and insects, protect wildlife and their habitats, and take into account non-timber components (Natural Resources Canada 1998).

[41] The sets of expressions in Vincent-Hartwick approach might be viewed as different versions of El Serafy's user cost

For example, in Alberta the most common form of forest tenure is the Forest Management Agreement (FMA). According to Anielski (1991), this tenure arrangement is designed to meet both the goals of the province and the producers. The province's goals are to provide sustained timber resources. The latter goals are to secure timber supply. Therefore, while a FMA provides the firm the right to harvest timber, it obliges the firm to manage future timber supplies through silviculture such as reforestation, stand management, and provisions of access roads at their own expenses.[42]

The firm's field operation is generally monitored by the provincial forest services based on the management plan that was proposed beforehand and then approved by the government. Under forest tenure arrangements, Annual Allowable Cuts (AAC) are set based on an assessment of long-run sustainable yield. Setting AAC levels involves fixing the volume of timber to be harvested every year using formulas that take into account the age distribution, volume and historic rate of growth of the original stand (Anielski 1991).

Tenure holders must pay stumpage fees and other forestry charges. Stumpage is generally a price per cubic meter that is levied on all timber cut by tenure holder. Methods of calculating stumpage are different among provinces. The rates, in particular set for large-size and long-term lease, may vary based on the negotiation between tenure holder and the province, the location of the lease, and the value of the end products (Forestry Canada 1991). However, once the negotiated stumpage fees are established, they are seldom changed for a specified period of time. Smaller tenures are usually sold to the highest bidder subject to a minimum price. Hence, there are difficulties in aggregating data on stumpage fees in each province and of knowing how stumpage reflects the market values of timber (Statistics Canada 1997). Furthermore, there is no guarantee that the current resource rent represented by stumpage tends to reflect the present values of future expected net income.

In this analysis, Canada's timber rent would alternatively be estimated from time series data on annual production by the forest industrial sector including the logging industry, the wood industries[43], and the paper and allied industries[44]. The timber rents from 1970 to 1993 are calculated in each of the logging industry, the wood industries, and the paper and allied

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method and the net price method (Vincent and Hartwick 1997).

[42] Most of provinces require tenure holders to ensure 'timely' regeneration after harvesting. B.C. and Alberta require most lease holders to do this at their own expenses (Forestry Canada 1991).

[43] The wood industries are defined as the aggregation of sawmill, planning mill and shingle mill products industries, veneer and plywood industries, sash, door and other millwork industries, wooden box and coffin industries, and other wood industries.

[44] The paper and allied industries are defined as the aggregation of pulp and paper industries, paper box and bag industries, other converted paper product industries.

industries, and finally the total forest industry figures, which combine the estimations from those three industries. According to Statistics Canada (1997), this grouping of the logging and secondary wood processing industries is necessary since many logging firms are integrated by the parent firms that belong to the second level industries. The logging companies do not sell timber to their parent mills, so that the selling prices they report do not necessarily reflect market prices for timber. The timber rent imputation based on the logging industry alone would be over or under estimated.[45]

3.3.3.2 Estimating Total Timber Rents

The basic idea of imputing the timber rent is to value the capital and labor forces input into forest industries at the appropriate shadow prices (Percy 1986). It subtracts the total return to these variable factors of production such as labor costs and opportunity cost of man-made capital from the value-added for forest industries.[46] The residual constitutes economic depreciation of timber resources or the timber rent. The timber rent is interpreted as the opportunity cost of harvesting timber today where the opportunity cost is the return that could be obtained by harvesting timber in the future. It also implies economic profits arising from the activity in the market.

The general formula to impute the total timber rent using value-added is given as:

$$\text{Total timber rent } (TR_t) = \text{value-added } (V_t) - \text{labor cost } (L_t) - \text{opportunity cost of man-made capital } (OC_t) \quad (1)$$

Value-added (V_t) is defined as the value-added of total activity, which is equivalent to the sum of value of manufacturing activity and non-manufacturing activity by Statistics Canada (1997). According to Statistics Canada (1997), the value-added in manufacturing activity is the value of net output as calculated by shipments plus the net change in inventories of goods in process and final goods, less the cost of materials, supplies, fuel and electricity purchased and used. It includes production subsidies and excludes indirect taxes such as stumpage and other forestry charges except for property and business taxes and administrative overhead costs.[47] On

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[45] If the reported selling price is low compared with the true market price, the timber rent is shifted to the buyer of timber. Therefore, the rent of the logging industry would be understated. Similarly, a high reported price would overstate the timber rent of the logging industry (Statistics Canada 1997).
[46] As summarized by Young and Serôa da Motta (1995) and also shown in introductory level macroeconomics textbook, value-added is the synthesis variable of the national accounts and the three approaches to it – output, income, and expenditure – from the key elements of the accounting framework. The concepts of income, output and expenditure represent different ways of looking at the production process but their values are identical.
[47] As Copithorne (1979) states, it is possible to adjust timber rent for provincial indirect taxes less subsidies but we do not do so, first because these items are rather small, and second because there is some danger of adjusting for stumpage twice in some provinces.

the other hand, the value-added in non-manufacturing activity is calculated by subtracting the corresponding commodity inputs from non-manufacturing revenues and outputs. It excludes rental revenues, dividends, and interests. The estimates of the value-added of total activity for the logging, wood, and paper and allied industries (V_t) are taken from Statistics Canada, Catalogue. No. 25-101, 25-202, 35-250, and 36-250.

The values of labor cost (L_t) in each industry are derived from the annual salaries and wages of total activity. They are also available from Statistics Canada, Catalogue. No. 25-101, 25-202, 35-250, and 36-250. The labor cost is defined as salaries and wages compiled before deduction for income tax and employee paid portions of both employee benefits and social insurance. They also include payments for regular work, overtime and paid leave as well as bonuses, etc (Statistics Canada 1997).

Opportunity cost of (man-made) capital is defined as interest forgone by the investors holding the net capital stock plus its depreciation.[48] This is generally regarded as a critical factor for imputing the resource rents. Opportunity cost of capital is the rate of return on invested capital that an investor requires in order to continue with the forestry investment rather than investing in another industry investment opportunity (Anielski 1991). In the long-run investment portfolio, the opportunity cost of capital rate of return has to be equal to the rate of return on the forestry investment.

Opportunity cost of man-made capital in year t is estimated using the following formula (Statistics Canada 1997):

Opportunity cost of capital (OC_t) = forgone interest (r_tK_t) + depreciation (D_t) *(2)*

where r_t = opportunity cost of capital interest rate; and K_t = end-year net capital stock of man-made capital in forest sector.

Opportunity cost of capital interest (r_t) is a measure of the risk associated with an investment in capital and represents the rate of return required by an investor that is sufficient to provide incentives to continue with that investment rather than reallocating capital elsewhere (Anielski 1991). This is taken as the average yield on 10-year industrial bonds (Copithorne 1979).[49] These data are obtained from CANSIM Series B14016, Bank of Canada. These data are available during the period of January 1948 to December 1988. Therefore, for the years after 1989, the

[48] The opportunity cost of capital is also called capital remuneration (Liu 1998) or treated as net profits (rVt) (Hartwick 1998) and real income (El Serafy 1989).

average rate of the 1980s are used (Appendix Table A.III-1). We will use 9.63 per cent in the 1970s and 12.98 per cent in the 1980s as the average of industrial bond yield average in each decade.

The net capital stock (K_t) data is taken from CANSIM Series D990389, D991037, and D991109, Statistics Canada, Investment and Capital Stock Division. The time series data of total geometric[50] end-year net stock for 1970-93 composed of building construction, engineering construction, and machinery and equipment, indicates fixed non-residential capital in Canada's logging industry, wood industries, and paper and allied industries.

The depreciation value of net capital stock (D_t) is an approximation of the value of man-made capital such as building construction, engineering construction, and machinery and equipment that is lost (or used up) in each year. The depreciation estimates are based on the current replacement cost of man-made capital stock input in the manufacturing activity. It is given as the following equation:

$$K_t = K_{t-1} - D_t + i_t \qquad (3)$$

Rearranging this to obtain D_t.,

$$D_t = K_{t-1} - K_t + i_t \qquad (3)'$$

where D_t = depreciation value of net capital stock of produced capital; K_t = end-year net capital stock of produced capital in year t; i_t = estimate of capital and repair expenditures in year t.

The data on capital and repair expenditures are taken from CANSIM Series D990373, D991021, and D991093, Statistics Canada, Investment and Capital Stock Division. According to National Forestry Database Program[51], capital expenditures include the cost of procuring, constructing, and installing new durable plants, machinery, and equipment, whether for replacement of worn or obsolete assets, as additions to existing assets or for lease or rent to others. In addition, they include all capitalized costs such as feasibility studies, architectural,

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[49] Percy (1986) had the same assumption, but added an arbitrary two percent premium risk in forestry investment to the bond value.

[50] Anielski (1991) explains the reason why he uses a geometric depreciation rate to impute net capital stock and depreciation value. "A geometric depreciation rate is one which has been developed by Statistics Canada. Statistics Canada surveyed and observed actual depreciation of capital investments and compared these actual figures against what would have been predicted if conventional accounting depreciation methods, including straight-line depreciation, were used. The results of the studies showed that the actual depreciation behavior was closest to a geometric depreciation rate, that is, a pattern of depreciation in which the productive efficiency of capital declines over time at an accelerated rate."

[51] http://www.nrcan.gc.ca/cfs/poj/iepb/nfpd.htm

legal, installation, and engineering fees, the value of capital assets put in place by firms, and capitalized interest charges on loans with which capital projects are financed. On the other hand, repair (and maintenance) expenditures include the portion of current or operating expenditures charged against revenue in the year incurred and made for the purpose of keeping the stock of fixed assets or productive capacity in good working condition during the life originally intended.

3.3.3.3 Results: Total Timber Rent Calculations

Table 3.2 to 3.5 shows the imputed total timber rents for the logging industry, the wood industries, the paper and allied industries, and the total forest industries in terms of current dollar base in the period 1970-93, respectively. The classification of total forest industries involves the aggregation of the logging industry and the secondary wood manufacturing activities; the wood industries and the paper and allied industries. These could present the component data for the value-added of total activity, salaries and wages, and opportunity cost of capital in each industrial classification. The last column in each table represents the total timber rent calculated using equation *(1)*. These imputed total timber rents are then replaced by values in terms of constant 1986 dollars using the Canadian GDP implicit producer price index (Appendix Table A.III-2) and summarized in Table 3.6 and Figure 3.3.

The results show that the average total timber rents in constant 1986 dollars for 1970-93 were $477.5 million in the logging industry, $960.9 million in the wood industries, and $596.0 million in the paper and allied industries. The table also presents the average rents of $2,011.5 million for the total forest industries that aggregates the primary and secondary wood processing industries. A significant contribution, approximately 80 per cent, to the total timber rent for the total forest industries comes from the secondary wood manufacturing sector.

Negative rent values are observed in the logging industry in 1982, in the wood industries in 1982 and 1991, and in the paper and allied industries in 1971, 1982, 1983, and 1990-1993 (Figure 3.3). The figure shows significant negative rents in the paper and allied industries in the early 1990s. Anielski (1991) suggested that these negative rents in the paper and allied industries come from the particular treatment of capital costs during a period of tremendous capital expansion in the industries.[52] However, it appears from Table 3.4 that the drastic increase of net capital stock investment in the paper and allied industries actually took place in the late 1980s before the large negative rents appear in 1991-93. As well, during the period, the paper and allied

[52] During the recession period of 1991-92, a large amount of equity capital entered the forest sector, while Canadian forest industries experienced significant financial losses. According to Natural Resources Canada (1996), the combination of an anticipated recovery in demand of forest products, low stock prices for forest companies, and general scarcity of stocks on equity markets led investors to direct large amounts of capital into forest sector. This equity capital allowed many forest companies to survive the recession in spite of abnormally high financial losses.

Table 3.2 Total Timber Rent for Logging Industry (Current Dollars)

(Millions of current dollars)

Year	Value-added	Labor cost	Opportunities cost of man-made capital				Total timber rent
			Interest rate	Net capital	Depreciation	Opportunity cost	
	(Vt)	(Lt)	(rt)	(Kt)	(Dt)	(Oct)	(TRt)
	1)	2)	3)	4)	5)	6)=3)*4)+5)	7)=1)-2)-6)
1970	694.0	412.0	0.0963	343.8	166.3	199.4	82.6
1971	698.0	413.0	0.0963	366.9	158.9	194.2	90.8
1972	829.0	458.0	0.0963	392.6	190.3	228.1	142.9
1973	1,109.0	606.0	0.0963	482.7	211.9	258.4	244.6
1974	1,244.0	707.0	0.0963	665.5	208.6	272.7	264.3
1975	1,126.0	712.0	0.0963	726.9	297.7	367.7	46.3
1976	1,348.0	773.0	0.0963	726.8	382.1	452.1	122.9
1977	1,440.0	844.0	0.0963	762.6	403.7	477.1	118.9
1978	1,647.0	973.0	0.0963	808.5	456.6	534.5	139.5
1979	2,053.0	1,115.0	0.0963	849.7	502.9	584.7	353.3
1980	2,049.0	1,179.0	0.1298	1,019.6	584.1	716.4	153.6
1981	1,883.0	1,192.0	0.1298	1,090.6	546.6	688.2	2.8
1982	1,650.0	1,032.0	0.1298	962.4	531.1	656.0	(38.0)
1983	2,151.0	1,219.0	0.1298	848.5	586.8	696.9	235.1
1984	2,191.0	1,324.0	0.1298	805.9	583.9	688.5	178.5
1985	2,187.0	1,294.0	0.1298	777.7	557.1	658.0	235.0
1986	2,297.0	1,313.0	0.1298	751.2	554.9	652.4	331.6
1987	3,340.0	1,532.0	0.1298	714.1	600.2	692.9	1,115.1
1988	3,378.0	1,623.0	0.1298	785.9	530.2	632.2	1,122.8
1989	3,657.0	1,759.0	0.1298	823.4	604.1	711.0	1,187.0
1990	3,197.0	1,633.0	0.1298	852.9	556.1	666.8	897.2
1991	2,914.0	1,534.0	0.1298	667.0	559.4	646.0	734.0
1992	3,272.0	1,635.0	0.1298	665.9	402.6	489.0	1,148.0
1993	3,908.0	1,701.0	0.1298	789.5	331.8	434.3	1,772.7

Source: Statistics Canada, Catalogue. No.25-101 and 25-202; and CANSIM Series B14016, D990389, and D990373.

Table 3.3 Total Timber Rent for Wood Industry (Current Dollars)

(Millions of current dollars)

Year	Value-added	Labor cost	Opportunities cost of man-made capital				Total timber rent
		wages	Interest rate	Net capital	Depreciation	Opportunity cost	
	(Vt)	(Lt)	(rt)	(Kt)	(Dt)	(Oct)	(TRt)
	1)	2)	3)	4)	5)	6)=3)*4)+5)	7)=1)-2)-6)
1970	802.0	552.0	0.0963	469.5	154.9	200.1	49.9
1971	1,017.0	638.0	0.0963	583.5	175.0	231.2	147.8
1972	1,422.0	771.0	0.0963	610.1	216.1	274.9	376.1
1973	1,977.0	939.0	0.0963	784.2	243.1	318.6	719.4
1974	1,748.0	1,038.0	0.0963	1,005.0	223.3	320.1	389.9
1975	1,690.0	1,071.0	0.0963	119.2	294.7	306.2	312.8
1976	2,236.0	1,353.0	0.0963	1,172.2	392.1	505.0	378.0
1977	2,762.0	1,558.0	0.0963	1,226.5	411.7	529.8	674.2
1978	3,550.0	1,821.0	0.0963	1,345.3	472.1	601.7	1,127.3
1979	4,021.0	2,074.0	0.0963	1,526.4	535.4	682.4	1,264.6
1980	3,466.0	2,217.0	0.1298	1,756.5	566.0	794.0	455.0
1981	3,442.0	2,286.0	0.1298	1,945.1	555.9	808.4	347.6
1982	2,708.0	2,102.0	0.1298	1,960.9	570.6	825.1	(219.1)
1983	3,993.0	2,724.0	0.1298	1,813.1	768.6	1,003.9	265.1
1984	4,051.0	2,541.0	0.1298	1,757.1	756.7	984.8	525.2
1985	4,688.0	2,740.0	0.1298	1,728.0	753.0	977.3	970.7
1986	5,523.0	2,856.0	0.1298	1,773.1	815.9	1,046.0	1,621.0
1987	6,548.0	3,304.0	0.1298	2,015.5	998.0	1,259.6	1,984.4
1988	6,277.0	3,517.0	0.1298	2,437.0	1,077.1	1,393.4	1,366.6
1989	6,449.0	3,655.0	0.1298	2,594.7	1,132.9	1,469.7	1,324.3
1990	5,728.0	3,565.0	0.1298	2,619.3	1,378.4	1,718.4	444.6
1991	4,979.0	3,207.0	0.1298	2,312.7	1,492.1	1,792.3	(20.3)
1992	6,058.0	3,401.0	0.1298	2,133.7	1,273.5	1,550.5	1,106.5
1993	8,343.0	3,705.0	0.1298	2,186.8	1,157.5	1,441.3	3,196.7

Source: Statistics Canada, Catalogue. No.25-202 and 32-250; and CANSIM Series B14016, D991037, and D991021.

Table 3.4 Total Timber Rent for Paper and Allied Industries (Current Dollars)

(Millions of current dollars)

Year	Value-added	Labor cost	Opportunities cost of man-made capital				Total timber rent
			Interest rate	Net capital	Depreciation	Opportunity cost	
	(Vt)	(Lt)	(rt)	(Kt)	(Dt)	(Oct)	(TRt)
	1)	2)	3)	4)	5)	6)=3)*4)+5)	7)=1)-2)-6)
1970	1,817.0	978.0	0.0963	2,323.1	511.8	735.5	103.5
1971	1,804.0	1,039.0	0.0963	2,575.3	529.3	777.3	(12.3)
1972	1,962.0	1,135.0	0.0963	2,744.0	539.7	803.9	23.1
1973	2,476.0	1,248.0	0.0963	2,921.8	535.0	816.4	411.6
1974	3,945.0	1,526.0	0.0963	3,392.3	497.4	824.1	1,594.9
1975	3,470.0	1,553.0	0.0963	3,660.9	686.1	1,038.6	878.4
1976	3,844.0	1,938.0	0.0963	3,931.7	916.0	1,294.6	611.4
1977	4,032.0	2,080.0	0.0963	4,164.9	1,056.2	1,457.3	494.7
1978	4,565.0	2,282.0	0.0963	4,365.4	1,060.0	1,480.4	802.6
1979	5,756.0	2,491.0	0.0963	4,772.5	1,143.8	1,603.4	1,661.6
1980	6,770.0	2,784.0	0.1298	5,498.3	1,426.4	2,140.1	1,845.9
1981	6,965.0	3,146.0	0.1298	6,919.7	1,664.2	2,562.4	1,256.6
1982	5,876.0	3,180.0	0.1298	7,959.9	1,736.3	2,769.5	(73.5)
1983	5,940.0	3,341.0	0.1298	7,688.3	2,160.4	3,158.3	(559.3)
1984	7,492.0	3,516.0	0.1298	7,744.1	2,139.7	3,144.9	831.1
1985	7,524.0	3,745.0	0.1298	8,616.8	2,297.7	3,416.2	362.8
1986	8,917.0	4,003.0	0.1298	9,149.1	2,736.3	3,923.9	990.1
1987	10,959.0	4,185.0	0.1298	10,030.2	3,267.8	4,569.7	2,204.3
1988	12,485.0	4,479.0	0.1298	11,709.4	3,744.2	5,264.1	2,741.9
1989	11,959.0	4,689.0	0.1298	15,119.2	4,087.5	6,050.0	1,220.0
1990	10,438.0	4,696.0	0.1298	16,898.7	4,640.8	6,834.3	(1,092.3)
1991	8,056.0	4,688.0	0.1298	16,880.6	5,136.8	7,327.9	(3,959.9)
1992	7,807.0	4,609.0	0.1298	16,628.0	4,424.5	6,582.8	(3,384.8)
1993	8,081.0	4,620.0	0.1298	16,123.1	4,763.9	6,856.7	(3,395.7)

Source: Statistics Canada, Catalogue. No.25-202 and 36-250; and CANSIM Series B14016, D991109, and D991093.

Table 3.5 Total Timber Rent for Total Forest Industries (Current Dollars)

(Millions of current dollars)

Year	Value-added	Labor cost	Opportunities cost of man-made capital				Total timber rent
			Interest rate	Net capital	Depreciation	Opportunity cost	
	(Vt)	(Lt)	(rt)	(Kt)	(Dt)	(Oct)	(TRt)
	1)	2)	3)	4)	5)	6)=3)*4)+5)	7)=1)-2)-6)
1970	3,313.0	1,942.0	0.0963	3,136.4	833.0	1,135.0	236.0
1971	3,519.0	2,090.0	0.0963	3,525.7	863.2	1,202.7	226.3
1972	4,213.0	2,364.0	0.0963	3,746.7	946.1	1,306.9	542.1
1973	5,562.0	2,793.0	0.0963	4,188.7	990.0	1,393.4	1,375.6
1974	6,937.0	3,281.0	0.0963	5,062.8	929.3	1,416.8	2,239.2
1975	6,286.0	3,336.0	0.0963	4,507.0	1,278.5	1,712.5	1,237.5
1976	7,428.0	4,064.0	0.0963	5,830.7	1,690.2	2,251.7	1,112.3
1977	8,234.0	4,482.0	0.0963	6,154.0	1,871.6	2,464.2	1,287.8
1978	9,762.0	5,076.0	0.0963	6,519.2	1,988.7	2,616.5	2,069.5
1979	11,830.0	5,680.0	0.0963	7,193.6	2,182.1	2,874.8	3,275.2
1980	12,285.0	6,180.0	0.1298	8,274.4	2,576.5	3,650.5	2,454.5
1981	12,290.0	6,624.0	0.1298	9,955.4	2,766.7	4,058.9	1,607.1
1982	10,234.0	6,314.0	0.1298	10,883.2	2,838.0	4,250.6	(330.6)
1983	12,084.0	6,987.0	0.1298	10,349.9	3,515.8	4,859.2	237.8
1984	13,734.0	7,381.0	0.1298	10,307.1	3,480.3	4,818.2	1,534.8
1985	14,399.0	7,779.0	0.1298	11,122.5	3,607.8	5,051.5	1,568.5
1986	16,737.0	8,172.0	0.1298	11,673.4	4,107.1	5,622.3	2,942.7
1987	20,847.0	9,021.0	0.1298	12,759.8	4,866.0	6,522.2	5,303.8
1988	22,140.0	9,619.0	0.1298	14,932.3	5,351.5	7,289.7	5,231.3
1989	22,065.0	10,103.0	0.1298	18,537.3	5,824.5	8,230.6	3,731.4
1990	18,363.0	9,894.0	0.1298	20,370.9	6,575.3	9,219.4	(750.4)
1991	15,949.0	9,429.0	0.1298	19,860.3	7,188.3	9,766.2	(3,246.2)
1992	17,137.0	9,645.0	0.1298	19,427.6	6,100.6	8,622.3	(1,130.3)
1993	20,232.0	10,026.0	0.1298	19,099.4	6,253.2	8,732.3	1,473.7

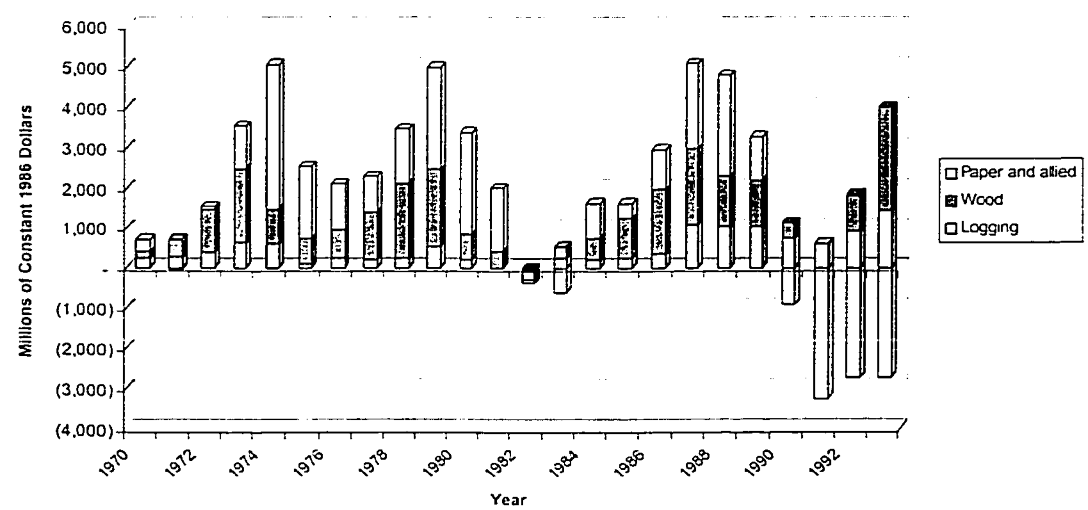
Source: Statistics Canada, Catalogue. No.25-101, 25-202, 35-250, and 36-250; and CANSIM Series B14016, D990389, D991037, D991109, D990373, D991221, and D991093.

Table 3.6 Summary of Total Timber Rents in Canada's Forest Sector (Constant 1986 Dollars)

(Millions of constant 1986 dollars)

Year	Logging industry	Secondary wood manufacturing			Total forest industries
		Wood industries	Paper and allied industries	Total	
	1)	2)	3)	4)=2)+3)	5)=1)+4)
1970	251.8	152.1	315.5	467.6	719.4
1971	267.8	436.0	(36.3)	399.7	667.6
1972	399.1	1,050.7	64.4	1,115.1	1,514.2
1973	627.2	1,844.6	1,055.5	2,900.0	3,527.3
1974	592.6	874.3	3,576.1	4,450.3	5,020.5
1975	94.5	638.4	1,792.6	2,431.0	2,525.5
1976	230.6	709.2	1,147.0	1,856.3	2,086.9
1977	210.0	1,191.1	874.1	2,065.2	2,275.2
1978	232.6	1,878.9	1,337.7	3,216.6	3,449.2
1979	535.3	1,916.1	2,517.6	4,433.7	4,962.4
1980	210.4	623.3	2,528.7	3,152.0	3,362.3
1981	3.5	429.7	1,553.3	1,983.0	1,986.5
1982	(43.3)	(249.3)	(83.6)	(332.9)	(376.2)
1983	254.7	287.2	(606.0)	(318.8)	257.6
1984	187.5	551.7	873.0	1,424.7	1,612.2
1985	240.5	993.6	371.4	1,364.9	1,605.4
1986	331.6	1,621.0	990.1	2,611.1	2,942.7
1987	1,065.1	1,895.3	2,105.3	4,000.6	5,065.7
1988	1,024.4	1,246.9	2,501.8	3,748.6	4,773.1
1989	1,033.1	1,152.6	1,061.8	2,214.4	3,247.5
1990	756.5	374.9	(921.0)	(546.1)	(632.7)
1991	602.1	(16.7)	(3,248.5)	(3,265.1)	(2,663.0)
1992	930.3	896.7	(2,742.9)	(1,846.3)	(916.0)
1993	1,421.6	2,563.5	(2,723.1)	(159.6)	1,262.0
Average	477.5	960.9	596.0	1,556.9	2,011.5

Figure 3.3 Contributions to Total Timber Rent: 1970-93



industries show a decline in value-added that might be caused by declining price of the products (Table 3.4).

One difficulty is how to treat these negative rents when economic depreciation of timber stocks is actually occurring. In this situation, negative rents imply a profit loss in the forest sector. However, the forest sector continued to operate and demand timber input during these periods of negative rents. This is because they are still covering variable costs (this can be confirmed by examining Table 3.4). However, this does not solve the problem of what to do with negative rents in the economic depreciation calculations.

Entering negative rent numbers into the formula does two things. First, if the forest is experiencing net growth (that is, growth is greater than depletion) and negative rents are placed in the formula (see equation (*10*) in this chapter), then positive numbers are generated from the economic depreciation formula, indicating that the forest is depreciating – a result that does not seem to make sense. Conversely, if the forest is experiencing net depletion and negative rents are entered into the formula, then negative numbers are generated and indicating appreciation. Again, this does not seem to be sensible. We assume that the firms continue to operate because they view these periods of negative net rents as a short term phenomena and they expect prices to increase in the future. Hence, we cannot use these short term negative rents directly in the economic depreciation calculations. The approach taken in this analysis is to enter the average rent over the time series into the economic depreciation formula for those years when rents are negative.

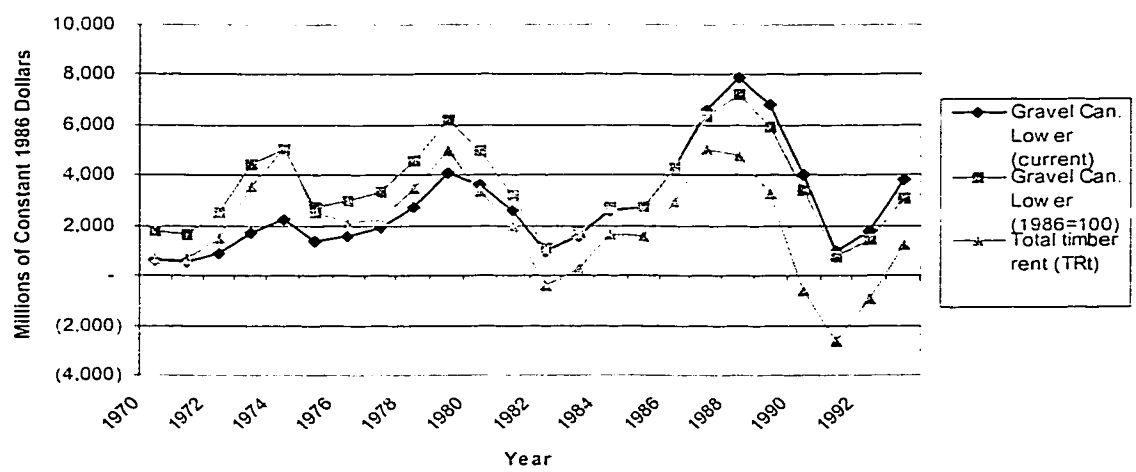
Table 3.7 and Figure 3.4 compare the total timber rent obtained above and imputed by Gravel, Statistics Canada, which is the only estimation of economic rent of timber resources available at the national level. Gravel's estimates, which includes both lower and upper bounds, is shown in current dollars. The lower bound is defined as the rent that includes both the estimated values for opportunity cost of capital composed by the return to man-made capital and the depreciation. The upper bound is defined as the rent that includes only the value of man-made capital depreciation. They are transformed into the figures in constant 1986 dollars using the Canadian GDP implicit price index.

While Gravel's lower bound estimation in constant 1986 dollars and our estimation indicate almost the same depreciation path through the examined period, the latter shows continuously smaller numbers than the former over time. The difference must be caused by the estimation of opportunity cost of capital using different data and assumptions, in particular about interest rate

Table 3.7 Comparative Studies of Total Timber Rents in Canada's Forest Sector (A)

Year	(Millions of current dollars) Gravel Canada (Lower bound)	(Millions of current dollars) Gravel Canada (Upper bound)	(Millions $ (1986=100)) Gravel Canada (Lower bound)	(Millions $ (1986=100)) Gravel Canada (Upper bound)	(Millions $ (1986=100)) Total timber rent (TRt)
1970	588.1	765.3	1,793.0	2,333.2	719.4
1971	550.3	747.3	1,623.3	2,204.4	667.6
1972	911.5	1,131.8	2,546.1	3,161.5	1,514.2
1973	1,725.2	1,966.1	4,423.6	5,041.3	3,527.3
1974	2,236.6	2,507.5	5,014.8	5,622.2	5,020.5
1975	1,351.7	1,680.7	2,758.6	3,430.0	2,525.5
1976	1,594.8	1,959.9	2,992.1	3,677.1	2,086.9
1977	1,891.9	2,286.2	3,342.6	4,039.2	2,275.2
1978	2,718.1	3,139.9	4,530.2	5,233.2	3,449.2
1979	4,073.3	4,528.8	6,171.7	6,861.8	4,962.4
1980	3,605.9	4,112.1	4,939.6	5,633.0	3,362.3
1981	2,611.8	3,185.1	3,228.4	3,937.1	1,986.5
1982	938.6	1,605.9	1,067.8	1,827.0	(376.2)
1983	1,580.6	2,313.4	1,712.5	2,506.4	257.6
1984	2,603.6	3,337.5	2,734.9	3,505.8	1,612.2
1985	2,695.3	3,437.2	2,758.8	3,518.1	1,605.4
1986	4,276.1	5,023.4	4,276.1	5,023.4	2,942.7
1987	6,628.5	7,401.7	6,330.9	7,069.4	5,065.7
1988	7,897.2	8,723.7	7,205.5	7,959.6	4,773.1
1989	6,799.2	7,722.4	5,917.5	6,721.0	3,247.5
1990	4,004.2	5,098.1	3,376.2	4,298.6	(632.7)
1991	956.2	2,171.1	784.4	1,781.1	(2,663.0)
1992	1,796.8	3,020.4	1,456.1	2,447.6	(916.0)
1993	3,837.2	5,077.5	3,077.1	4,071.8	1,262.0)
Average			3,502.6	4,246.0	2,011.5

Figure 3.4 Comparative Studies of Total Timber Rents in Canada's Forest Sector (A): 1970-93



(r_t), since both are using the same data in terms of the value-added and labor costs in forest industries.

The estimation of the total timber rent above is conceptually a very basic method compared with two other methodologies: the net price approach, and the Vincent-Hartwick (V-H) approach.[53] As the most important shortcoming, the total timber rent calculated using value-added does not take into account any growth factor of timber resources at all as shown in equation *(2)* in Chapter 2. These two methods are conceptual attempts to estimate the timber rent more precisely.

3.3.3.4 Net Price Approach

The net price approach is based on total Hotelling rents attributed to exploitation of a resource in a given year under the assumption of perfect competition. This approach assumes an optimal extraction path with unit rents rising by the Hotelling efficiency rule. Hotelling's rent (or the net price), $p - mc$, represents profit earned on the marginal unit exploited at the expense of reduced value of the asset. In this case, the expected rate of growth of the unit rent would be equal to the discount rate. Total Hotelling rent (or the total profit), $(p - mc)q$, in a given year can be regarded as economic depreciation, that is, $V_t - V_{t+1} = R_t = (p - mc)q_t$, which then is deducted from resource accounts.

In the net price approach, while returns earned in capital market have been included, other expenses such as taxes, duties, and royalties are excluded (Repetto et al. 1989). The value of the resource stock could be calculated as the unit current rent of resource times the size of the stock. The stock size of resource would be modified by accounting for changes in the level of proved reserve with discovery (non-renewable resources) and with growth (renewable resources). In the next two subsections two versions of the net price approach are implemented to estimate economic depreciation of Canada's timber stocks.

3.3.3.5 Net Price Approach (NP(1)): Case of Timber Resource Asset

The net price approach implemented in this subsection considers the harvest and growth of timber stocks. To define the net price approach, suppose that the unit output price (p) is constant

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[53] El Serafy's user cost approach is another important methodology used to estimate economic depreciation of natural resources. However, in the case of renewable resources sustained infinitely like Canada's timber resources, this method is difficult to apply without depending on more complicated forecast models to obtain a projection of future timber rents. In this point, two other methods the net price approach and the Vincent-Hartwick approach are simpler and more practical approaches.

and the total harvesting costs ($C(q_t)$) increase as current harvest (q_t) increases.[54] Taking the value of timber resources ($V(S_t)$) in year t in infinite time, based on the opening stock size (S_t), as the discrete-time present value of the sum of future expected resource rents:

$$V(S_t) = (pq_t - C(q_t)) + (pq_{t+1} - C(q_{t+1}))/(1+r) + (pq_{t+2} - C(q_{t+2}))/(1+r)^2 + \dots \qquad (4)$$

where S_t = opening stock size of timber resources in year t; $pq_t - C(q_t)$ = future expected economic rent in year t ; and r = social discount rate.

Note that equation *(4)* is not expressed in terms of S_t. To express equation *(4)* in terms of S_t, we use the identity of the current closing stock (S_{t+1}) (or the next year opening stock size) of timber resources in year t:

$$S_{t+1} = S_t - q_t + g_t \qquad (5)$$

This is expressed as the current year opening stock (S_t) minus the current year harvest and natural losses (q_t) plus the current growth or annual increment (CAI) of the timber stock (g_t).

The change in timber stock size ($\Delta S_t = S_{t+1} - S_t$) in the current year t is expressed as a function of (q_t) and (g_t):

$$dS_t/dt = S_{t+1} - S_t = -q_t + g_t \qquad (6)$$

By substituting $q_t = S_t - S_{t+1} + g_t$ obtained from *(5)* into *(4)*, we will obtain $V(S_t)$ expressed in the way of S_t:

$$\begin{aligned} V(S_t) = {} & [p(S_t - S_{t+1} + g_t) - C(S_t - S_{t+1} + g_t)] \\ & + [p(S_{t+1} - S_{t+2} + g_{t+1}) - C(S_{t+1} - S_{t+2} + g_{t+1})]/(1+r) \\ & + [p(S_{t+2} - S_{t+3} + g_{t+2}) - C(S_{t+2} - S_{t+3} + g_{t+2})]/(1+r)^2 + \dots \qquad (7) \end{aligned}$$

First note that change in value of a stock can be approximated using a first-order Taylor-series expansion around $V(S_t)$:

$$V(S_{t+1}) = V(S_t) + V'(S_t)[S_{t+1} - S_t] \qquad (8)$$

[54] This implies the cost of felling, transporting and processing related to harvesting.

To obtain the expression of economic depreciation of timber asset (D_t), we can rearrange *(8)* as:

$$D_t = V(S_t) - V(S_{t+1}) = V'(S_t)[S_t - S_{t+1}] \qquad (9)$$

Based on *(7)*, we could obtain the first derivative of $V(S_t)$ with respect to S_t.

$$V'(S_t) = p - C'(q_t) \qquad (10)$$

By utilizing the information derived in *(10)* and setting up $[S_t - S_{t+1}] = [q_t - g_t]$, we can obtain the following formula from *(9)*:

$$D_t = [p - C'(q_t)][q_t - g_t] \qquad (11)$$

This demonstrates that economic depreciation of timber resource (or the total timber rent) is the product of the net annual change in timber stock multiplied by Hotelling rent. We will call this expression of the net price approach (1), NP(1).

Given the difficulty of obtaining the unit marginal harvesting costs, most previous attempts to calculate resource rents have used the unit average cost as an approximation, as applied by Repetto et al. (1989) and Hartwick (1990).[55] If assuming that the unit average variable costs are approximately equivalent to the unit marginal costs, then equation *(11)* becomes:

$$\begin{aligned} D_t &= [p - C'(q_t)][q_t - g_t] \\ &\cong [p - C(q_t)/q_t][q_t - g_t] \qquad (12) \end{aligned}$$

Since $pq_t - C(q_t)$ is equal to the total timber rent in year t (TR_t), equation *(12)* could be written:

$$D_t = \frac{TR_t}{q_t}[q_t - g_t] \qquad (13)$$

Consequently, we can simply use the total timber rent (constant 1986 dollars) that have already been estimated using value-added (Table 3.6) without collecting the data of the unit price of harvested timber and the unit average variable cost of timber harvesting. The volumes of

[55] According to Vincent and Hartwick (1997), this is also based on the assumption that the cost function is linear in the quantity extracted.

current harvest (q_t) and CAI (g_t) are available from physical timber accounts. In Table 3.1, the volume of (q_t) could be regarded as the annual depletion of timber resources, including not only harvest but also other causes of depletion such as mortality, fire damage, and road construction. The volume of (g_t) is simply determined as the volume of regeneration in year t.

A weakness of this approach is that the size of the timber stock may effect CAI (g_t). If CAI (g_t) is a function of the total opening stock (S_t), then changes in stock will impact CAI. These effects are accounted for in the next section.

3.3.3.6 Net Price Approach (NP(2)): Accounting for the Growth Stock Effect

In this section, it is assumed that CAI (g_t) is related to the timber stock size. This is known as a stock effect. Stock effects are also often used to model the effect of a change in the stock size on extraction costs (not on CAI). Generally, the more natural resources we use today, the fewer will be available for use in the future and the more severe will be the effects of depleted stocks on future extraction costs (Howe 1979). In the estimates of economic depreciation that follow, it is assumed that there is no effect related to harvesting costs and that the cost function is affected only by the amount of harvesting, $C(q_t)$. However, we will assume that CAI (g_t) is related to timber stock size, which we will call stock effect.

In this analysis, CAI is defined as a dependent variable of the opening stock level (S_t) or $g_t(S_t)$. The marginal growth with respect to timber stock size (S_t), dg_t/dS_t, may be negative or positive depending on stock size and the age-class distribution of the forest inventory. If the inventory has many older trees, then CAI will tend to decline as the stock increases, and vice versa. Canada's forests are characterized by a large amount of mature or overmature trees. Hence, we expect that the stock effect will be negative because the timber growth (CAI) rate declines as the timber grows to maturity. It is assumed that the function relating the timber stock level to CAI has a concave shape (Figure 3.5).

Table 3.8 shows changes calculated in CAI and changes in opening timber stock size using physical timber accounts (Table 3.1) during the period 1970-93. The stock effect is calculated using the formula:

$$dg_t/dS_t \approx \Delta CAI/\Delta \text{stock size}$$

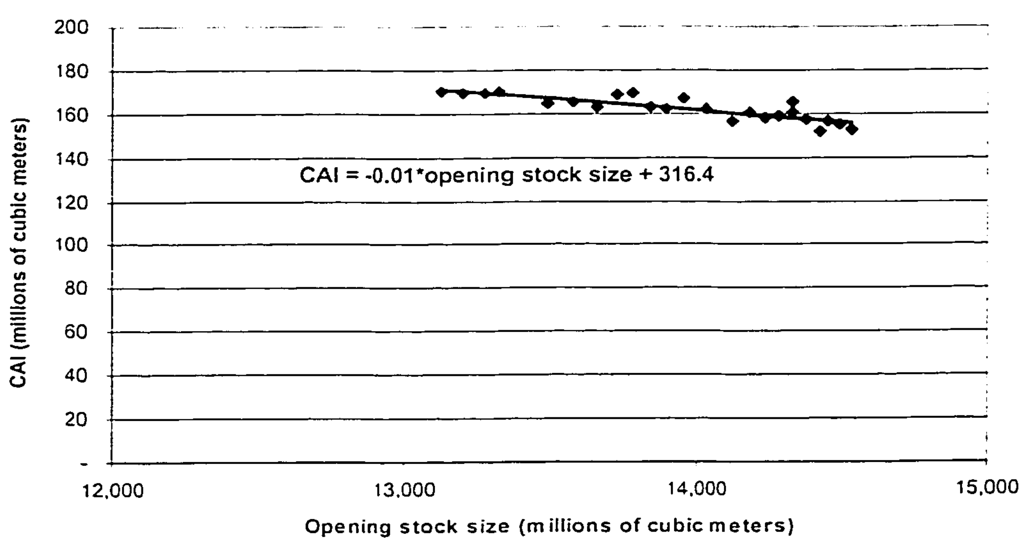
$$\approx (g_t - g_{t-1})/(S_t - S_{t-1}) \qquad (14)$$

Table 3.8 Growth Stock Effect

	(Thousands of cubic meters)				
Year	Opening stock	Regeneration (=CAI)	Growth stock effect		
			Change of stock 1)	Change of CAI 2)	Stock effect 3)=2)/1)
1970	14,538,759.4	152,382.3	(40,542.7)		
1971	14,498,216.7	154,818.8	(40,096.8)	2,436.50	-0.06
1972	14,458,119.9	156,729.9	(27,271.3)	1,911.10	-0.05
1973	14,430,848.6	151,766.8	(44,068.9)	(4,963.10)	0.18
1974	14,386,779.7	157,139.2	(48,492.5)	5,372.40	-0.12
1975	14,338,287.2	165,223.7	(1,100.7)	8,084.50	-0.17
1976	14,337,186.5	160,795.8	(45,096.4)	(4,427.90)	4.02
1977	14,292,090.1	158,820.9	(50,518.0)	(1,974.90)	0.04
1978	14,241,572.1	157,971.9	(50,915.8)	(849.00)	0.02
1979	14,190,656.3	160,841.3	(59,384.0)	2,869.40	-0.06
1980	14,131,272.3	156,698.4	(97,155.1)	(4,142.90)	0.07
1981	14,034,117.2	162,416.5	(82,127.7)	5,718.10	-0.06
1982	13,951,989.5	167,182.3	(57,995.2)	4,765.80	-0.06
1983	13,893,994.3	162,043.6	(57,772.7)	(5,138.70)	0.09
1984	13,836,221.6	163,034.3	(57,614.6)	990.70	-0.02
1985	13,778,607.0	169,633.5	(53,312.2)	6,599.20	-0.11
1986	13,725,294.8	168,812.4	(67,911.8)	(821.10)	0.02
1987	13,657,383.0	162,796.6	(86,051.2)	(6,015.80)	0.09
1988	13,571,331.8	165,128.9	(84,939.1)	2,332.30	-0.03
1989	13,486,392.7	164,330.1	(164,757.4)	(798.80)	0.01
1990	13,321,635.3	170,352.6	(45,831.4)	6,022.50	-0.04
1991	13,275,803.9	169,097.3	(74,438.4)	(1,255.34)	0.03
1992	13,201,365.5	169,799.1	(75,491.0)	701.83	-0.01
1993	13,125,874.6	170,500.9	(76,479.2)	701.83	-0.01

Source: Statistics Canada, Econnections, 1997

Figure 3.6 Growth Stock Effect of Canada's Forests: 1970-93



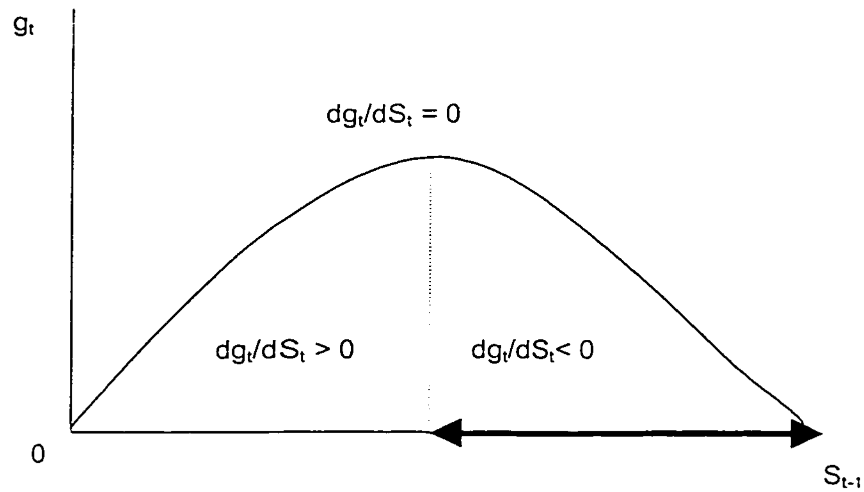


Figure 3.5 Marginal Growth Affected by the Timber Stock Size

Figure 3.6 presents the empirical relationship between both changes in CAI and stock size. Although dg_t/dS_t was expected to be negative ($dg_t/dS_t < 0$) because of mature forests, positive numbers were shown in ten of the twenty-three years. Furthermore, in 1976 the very large positive growth stock effect, 4.02, is observed due to the small change of timber stock in 1975 (–1,100.7 millions of cubic meters) and the large decline of CAI from 1975 to 1976 (– 4,427.9 millions of cubic meters). To smooth this irregularity, the estimated slope from the relationship of CAI and the opening stock size, – 0.01, is used as the growth stock effect figure. This negative number could support the hypothesis that the linear relationship between both changes in CAI and stock size in Canada's forest might locate somewhere on the line of $dg_t/dS_t < 0$ in Figure 3.5.

How would the expression of economic depreciation be changed if we take into account the growth stock effect? Under the same assumptions in terms of (p) and ($C(q_t)$) as NP(1), the discrete-time capitalized value of timber resources in year t ($V(S_t)$) and in year t+1 ($V(S_{t+1})$) in infinite time is expressed as:

$$V(S_t) = (pq_t - C(q_t)) + (pq_{t+1} - C(q_{t+1}))/(1+r) + (pq_{t+2} - C(q_{t+2}) - R_{t+2})/(1+r)^2 + \ldots\ldots \quad (15)$$

$$V(S_{t+1}) = (pq_{t+1} - C(q_{t+1})) + (pq_{t+2} - C(q_{t+2}))/(1+r) + (pq_{t+3} - C(q_{t+3}) - R_{t+3})/(1+r)^2 + \ldots\ldots \quad (16)$$

S_{t+1} denotes the current closing stock size of timber resources in year t. It is expressed as:

$$S_{t+1} = S_t - q_t + g_t(S_t) \quad (17)$$

The change in timber stock size ($\Delta S_t = S_{t+1} - S_t$) from the previous year t-1 to the current year t is expressed as a function of (q_t) and (g_t):

$$dS_t/dt = S_{t+1} - S_t = -q_t + g_t(S_t) \qquad (18)$$

To express equation *(15)* in terms of S_t, we substitute $q_t = S_t - S_{t+1} + g_t(S_t)$ obtained from *(17)* into *(15)*:

$$\begin{aligned} V(S_t) = {} & [p(S_t - S_{t+1} + g_t(S_t)) - C(S_t - S_{t+1} + g_t(S_t)] \\ & + [p(S_{t+1} - S_{t+2} + g_{t+1}(S_{t+1})) - C(S_{t+1} - S_{t+2} + g_{t+1}(S_{t+1}))]/(1+r) \qquad (19) \\ & + [p(S_{t+2} - S_{t+3} + g_{t+2}(S_{t+2})) - C(S_{t+2} - S_{t+3} + g_{t+2}(S_{t+2}))]/(1+r)^2 + \ldots\ldots \end{aligned}$$

By using the first-order Taylor-series expansion around $V(S_t)$ again, $V(S_{t+1})$can be expressed as:

$$V(S_{t+1}) = V(S_t) + V'(S_t)[S_{t+1} - S_t] \qquad (20)$$

Rearranging equation *(20)*, we can obtain an expression for economic depreciation of timber resources:

$$D_t = V(S_t) - V(S_{t+1}) = V'(S_t)[S_t - S_{t+1}] \qquad (21)$$

Based on equation *(19)*, the first derivative of $V(S_t)$ with respect to S_t becomes:

$$\begin{aligned} V'(S_t) &= p[1 + dg_t/dS_t] - C'(q_t)[1 + dg_t/dS_t] \\ &= [p - C'(q_t)][1 + dg_t/dS_t] \qquad (22) \end{aligned}$$

Utilizing *(22)* in *(21)*, we can obtain:

$$D_t = [p - C'(q_t)][1 + dg_t/dS_t][S_t - S_{t+1}] \qquad (23)$$

The change of the stock level, $S_t - S_{t+1}$, in year t is equivalent to $[q_t - g_t(S_t)]$. By substituting this term into equation *(23)*, we arrive at:

$$D_t = [p - C'(q_t)][1 + dg_t/dS_t][q_t - g_t(S_t)] \qquad (24)$$

This equation implies that economic depreciation of timber resources is the product of Hotelling's rent, the growth stock effect, and the net annual change in the timber stock. While it is basically the same model structure as NP(1), it includes a new factor that affects the calculation of the timber rent, that is the growth stock effect. We will call this expression the net price approach (2), NP(2). NP(2) leads to a downward adjustment for economic depreciation to account for the fact that CAI is increasing in a certain range while the timber resource stock is decreasing in Canada's forests (Table 3.1 and Table 3.8). The increase in CAI during the sample period occurs because of harvest in old growth or high volume stock forests.[56]

Replacing the term for the unit marginal cost with the unit average variable costs in equation *(24)* yields:

$$D_t \cong [p - c(q_t)/q_t][1 + dg_t/dS_t][q_t - g_t(S_t)] \qquad (25)$$

Since $pq_t - C(q_t)$ is equal to the total timber rent in year t (TR_t) again, equation *(25)* for NP(2) can be expressed as:

$$D_t = \frac{TR_t}{q_t}[q_t - g_t(S_t)][1 + dg_t/dS_t] \qquad (26)$$

3.3.3.7 Results: NP(1) and NP(2)

The results of applying NP(1) and NP(2) to Canada's forest sector are shown in Table 3.9 and 3.10. All figures are shown in constant 1986 dollars using the Canadian GDP implicit price index. The estimates are for all forest industries, combining the logging industry, the wood industries, and the paper and allied industries. Hence, it is assumed that timber is harvested by the aggregate forest industries (not the logging industry alone). Table 3.9 and 3.10 also presents information needed to calculate equation *(13)* for NP(1) and equation *(26)* for NP(2). The final column in each table show the estimation results for economic depreciation using each method.

The average economic depreciation values during the period 1970-93 were $705.4 million for NP(1) and $698.4 million for NP(2). As expected, NP(2)'s results were slightly smaller than NP(1)'s because of the growth stock effect (the opening timber stock has been declining as in Table 3.1 or 3.8). Negative values are observed in the exactly same years between NP(1) and NP(2), 1982 and 1990-93. Economic depreciation using NP(1) and (NP(2) show the same depreciation path. The estimated results do not show a significant difference between the

[56] This hypothesis is supported by the fact that mortality volume is decreasing (Table 4.1).

Table 3.9 Economic Depreciation for Total Forest Industries (NP(1))

Year	(Millions $ (1986=100)) Total timber rent	(Thousands of cubic meters) Annual depletion	Current annual increment (CAI)	(Millions $ (1986=100)) Economic depreciation
	1)	2)	3)	4)=[1)/2)]*[2)-3)]
1970	719.4	192,925.0	152,382.3	151.2
1971	667.6	194,925.6	154,818.8	137.4
1972	1,514.2	184,001.1	156,729.9	224.4
1973	3,527.3	195,835.9	151,766.8	793.7
1974	5,020.5	205,631.6	157,139.2	1,183.9
1975	2,525.5	166,324.5	165,223.7	16.7
1976	2,086.9	205,892.2	160,795.8	457.1
1977	2,275.2	209,338.9	158,820.9	549.1
1978	3,449.2	208,887.6	157,971.9	840.7
1979	4,962.4	220,225.3	160,841.3	1,338.1
1980	3,362.3	253,753.3	156,698.4	1,286.0
1981	1,986.5	244,635.3	162,416.5	667.6
1982	2,011.5*	225,086.5	167,182.3	517.5
1983	257.6	219,816.4	162,043.6	67.7
1984	1,612.2	220,649.0	163,034.3	421.0
1985	1,605.4	222,945.7	169,633.5	383.9
1986	2,942.7	236,724.3	168,812.4	844.2
1987	5,065.7	248,847.8	162,796.6	1,751.7
1988	4,773.1	250,068.0	165,128.9	1,621.2
1989	3,247.5	329,087.6	164,330.1	1,625.9
1990	2,011.5*	216,184.0	170,352.6	426.4
1991	2,011.5*	243,535.6	169,097.3	614.8
1992	2,011.5*	245,290.1	169,799.1	619.1
1993	1,262.0	246,980.2	170,500.9	390.8
Average				705.4

Note: * is the average timber rent of total forest industries during the period 1970-93.

Table 3.10 Economic Depreciation for Total Forest Industries (NP(2))

Year	(Millions $ (1986=100)) Total timber rent	(Thousands of cubic meters) Annual depletion	Current annual increment (CAI)	Stock effect	(Millions $ (1986=100)) Economic depreciation
	1)	2)	3)	4)	5)=[1)/2)]*[2)-3)]*[1+4)]
1970	719.4	192,925.0	152,382.3	-0.01	149.7
1971	667.6	194,925.6	154,818.8	-0.01	136.0
1972	1,514.2	184,001.1	156,729.9	-0.01	222.2
1973	3,527.3	195,835.9	151,766.8	-0.01	785.8
1974	5,020.5	205,631.6	157,139.2	-0.01	1,172.1
1975	2,525.5	166,324.5	165,223.7	-0.01	16.5
1976	2,086.9	205,892.2	160,795.8	-0.01	452.5
1977	2,275.2	209,338.9	158,820.9	-0.01	543.6
1978	3,449.2	208,887.6	157,971.9	-0.01	832.3
1979	4,962.4	220,225.3	160,841.3	-0.01	1,324.7
1980	3,362.3	253,753.3	156,698.4	-0.01	1,273.1
1981	1,986.5	244,635.3	162,416.5	-0.01	661.0
1982	2,011.5*	225,086.5	167,182.3	-0.01	512.3
1983	257.6	219,816.4	162,043.6	-0.01	67.0
1984	1,612.2	220,649.0	163,034.3	-0.01	416.8
1985	1,605.4	222,945.7	169,633.5	-0.01	380.1
1986	2,942.7	236,724.3	168,812.4	-0.01	835.8
1987	5,065.7	248,847.8	162,796.6	-0.01	1,734.2
1988	4,773.1	250,068.0	165,128.9	-0.01	1,605.0
1989	3,247.5	329,087.6	164,330.1	-0.01	1,609.6
1990	2,011.5*	216,184.0	170,352.6	-0.01	422.2
1991	2,011.5*	243,535.6	169,097.3	-0.01	668.7
1992	2,011.5*	245,290.1	169,799.1	-0.01	612.9
1993	1,262.0)	246,980.2	170,500.9	-0.01	386.9
Average					698.4

Note: * is the average timber rent of total forest industries during the period 1970-93.

imputed economic depreciation using NP(1) and NP(2) due to the relatively small impact of the marginal growth stock effect in the calculation of NP(2).

Table 3.11and Figure 3.7 compare the economic depreciation estimates using NP(1) and NP(2) with the values obtained using value-added and with those imputed by Gravel (1986 = 100). These clearly show that the estimated results from NP(1) and NP(2) are almost identical and that the total timber rents and Gravel's estimation fixed in constant 1986 dollars overstate economic depreciation values compared to those using NP(1) and NP(2). This is because the total timber rent and Gravel's estimation are based on only gross annual depletion, which is due to timber harvesting and natural losses.

3.3.3.8 Regeneration Costs

In NP(1) and NP(2), economic depreciation of timber resources does not take into account regeneration costs, in spite of including CAI term in the stock. In those approaches, the cost was simply dealt with as the unit marginal harvesting costs ($C'(q_t)$), which was the costs of felling, transporting and processing related to harvesting. However, CAI (g_t) significantly relates to regeneration treatments accompanied by regeneration costs, or more accurately silviculture costs. Basic silviculture encompasses expenditures on forest protection to site preparation after logging, and on artificial regeneration and the management when natural regeneration is unlikely to occur or fails to take place within a reasonable time (Percy 1986).

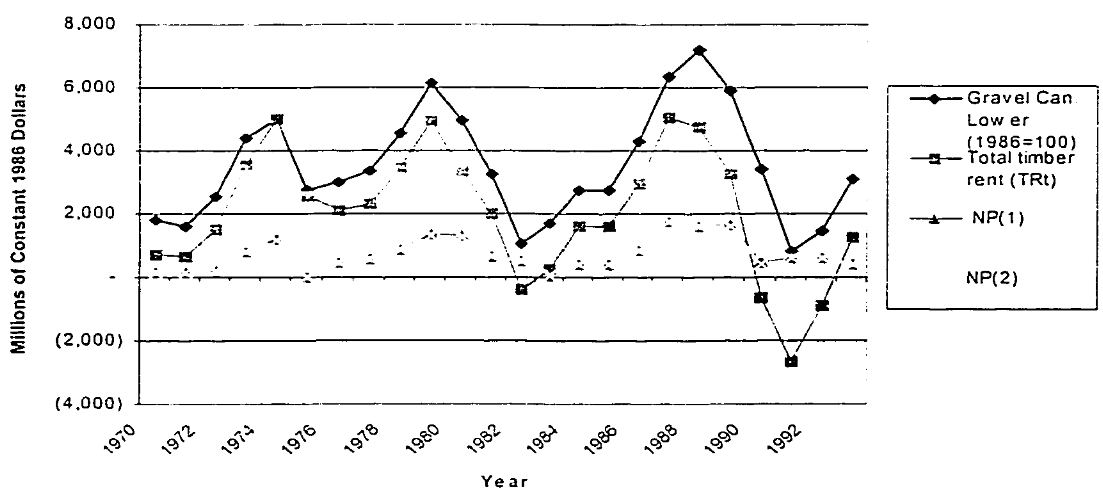
According to Percy (1986), intensive forest management provides the possibility of offsetting the declines in timber production accompanying the shift to second-growth from old-growth. It covers a variety of treatments directed at improving the growth of forest base. Broadly defined it includes research into genetically superior trees and increased nursery production of such seedlings, backlog reforestation of previously harvested areas where natural reforestation has failed, and a variety of stand-tending techniques applied primarily to second-growth stands. These latter techniques include (pre)commercial thinning, selection (uneven-aged management), and fertilization (Statistics Canada 1997).

If we account for regeneration costs (R_t) in the current year, then CAI in the stock (g_t) is defined as $g_t(S_t, R_t)$. It is assumed that the marginal growth of silviculture costs, dg_t/dR_t, in year t is zero ($dg_t/dR_t = 0$). The assumption is reasonable because there is a lag effect between changes in CAI and regeneration treatments. Hence, regeneration costs are not incorporated into the net price approaches to calculate economic depreciation. However, regeneration costs would

Table 3.11 Comparative Studies of Economic Depreciation in Canada's Forest Sector (B)

Year	Gravel Canada (Millions $ (1986=100)) (Lower bound)	(Upper bound)	Total timber rent (TRt)	NP(1)	NP(2)
1970	1,793.0	2,333.2	719.4	151.2	149.7
1971	1,623.3	2,204.4	667.6	137.4	136.0
1972	2,546.1	3,161.5	1,514.2	224.4	222.2
1973	4,423.6	5,041.3	3,527.3	793.7	785.8
1974	5,014.8	5,622.2	5,020.5	1,183.9	1,172.1
1975	2,758.6	3,430.0	2,525.5	16.7	16.5
1976	2,992.1	3,677.1	2,086.9	457.1	452.5
1977	3,342.6	4,039.2	2,275.2	549.1	543.6
1978	4,530.2	5,233.2	3,449.2	840.7	832.3
1979	6,171.7	6,861.8	4,962.4	1,338.1	1,324.7
1980	4,939.6	5,633.0	3,362.3	1,286.0	1,273.1
1981	3,228.4	3,937.1	1,986.5	667.6	661.0
1982	1,067.8	1,827.0	(376.2)	517.5	512.3
1983	1,712.5	2,506.4	257.6	67.7	67.0
1984	2,734.9	3,505.8	1,612.2	421.0	416.8
1985	2,758.8	3,518.1	1,605.4	383.9	380.1
1986	4,276.1	5,023.4	2,942.7	844.2	835.8
1987	6,330.9	7,069.4	5,065.7	1,751.7	1,734.2
1988	7,205.5	7,959.6	4,773.1	1,621.2	1,605.0
1989	5,917.5	6,721.0	3,247.5	1,625.9	1,609.6
1990	3,376.2	4,298.6	(632.7)	426.4	422.2
1991	784.4	1,781.1	(2,663.0)	614.8	698.7
1992	1,456.1	2,447.6	(916.0)	619.1	612.9
1993	3,077.1	4,071.8	1,262.0	390.8	386.9
Average	3,502.6	4,246.0	2,011.5	705.4	698.4

Figure 3.7 Comparative Studies of Economic Depreciation in Canada's Forest Sector (B): 1970-93



be incorporated in estimates of economic depreciation. This is more feasible in the V-H approach which is discussed in the next section.

3.3.3.9 Vincent-Hartwick (V-H) Approach: Accounting for the Age Effect

Vincent and Hartwick (1997) proposed an alternative method to calculate economic depreciation of timber resources.[57] This approach takes into account the number of years that a forest must grow before it reaches maturity. Vincent and Hartwick argued that the net price approach is valid only in the cases where newly regenerated resources can be harvested immediately. This is not the case with timber stocks. Timber resources usually have a long time lag between regeneration and maturity and thereby show a mixture of different age classes (Hassan 2000). Hence, mature forests present different values than immature forests that are not immediately ready for harvesting due to quality differences and the opportunity cost letting immature timber to grow to maturity (Vincent and Hartwick 1997).

To allow for the age effect (remaining time in years to maturity) in timber resources and the age-class distribution of the timber stocks in the economic depreciation calculation, Vincent and Hartwick (1997) defined two equations for capitalized value of timber assets: one for mature forests (V_T) and another for immature forests (V_t). Note that T refers to the age at which forest becomes harvested (optimal rotation) in the Vincent-Hartwick formulation and $t < T$ refers to the age of immature forest. Assuming that the harvesting cost function is linear, the capitalized values per hectare of mature and immature forests are given as:

$$V_T = [(p - c)q(T)] + [(p - c)q(T)]/[(1 + r)^T - 1]$$
$$= [(p - c)q(T)]/[1 - (1 + r)^{-T}] \qquad (27)$$

$$V_t = \{[(p - c)q(T)] + [(p - c)q(T)]/[(1 + r)^T - 1]\}/(1 + r)^{T-t}$$
$$= [(p - c)q(T)](1 + r)^{t-T}/[1 - (1 + r)^{-T}] \qquad (28)$$

where T = time of maturity (optimal rotation age); p = unit output price at maturity; c = unit average harvesting costs at maturity; q(T) = harvested volume per hectare in year T; and r = social discount rate.

In equations *(27)* and *(28)*, it is assumed that the unit output prices (p) and the unit average harvesting costs (c) are constant over time. Hence, they do not account for changes in asset

[57] In Vincent and Hartwick (1997), two sets of expressions are called as the correct version of El Serafy's user cost method (equations *(35)* and *(36)* in this thesis) and the correct version of the net price method (equations *(39)* and *(40)* in this thesis) to apply to timber resources.

value due to price fluctuations.[58] They also assume that: 1) forests are even-aged (all standing trees are the same age); 2) all standing trees are harvested every T years (i.e. at the optimal rotation age); and 3) the land remains permanently in forest use.

Based on equation *(27)* and *(28)*, the economic depreciation of one hectare of mature forest (D_T) and immature forest (D_t) is expressed as follows:

$$D_T = V(T) - V(1)$$
$$= [(p-c)q(T)] + [(p-c)q(T)]/[(1+r)^T - 1] - \{[(p-c)q(T)] + [(p-c)q(T)]/[(1+r)^T - 1]\}/(1+r)^{T-1}$$
$$= [(p-c)q(T)] + [(p-c)q(T)]/[(1+r)^T - 1] - [(p-c)q(T)](1+r)^{1-T}/[1-(1+r)^{-T}]$$
$$= [(p-c)q(T)][1-(1+r)^{1-T}]/[1-(1+r)^{-T}] \quad (29)$$

$$D_t = -rV(t)$$
$$= -r\{\{[(p-c)q(T)] + [(p-c)q(T)]/[(1+r)^T - 1]\}/(1+r)^{T-t}\}$$
$$= -r\{[(p-c)q(T)](1+r)^{t-T}/[1-(1+r)^{-T}]\} \quad (30)$$

For economic depreciation of immature forest (D_t), $t < T$ is considered. This set of equations is referred as the Vincent-Hartwick (V-H) approach. From equation *(29)* and *(30)*, the V-H approach shows that economic depreciation of timber resources should reflect both the exploitation of rents from the current harvest of forests, which decreases the capitalized value, and the shifting of rents from future harvests toward the present, which increases the capitalized value (Vincent and Hartwick 1997). Note that equation *(30)* does not include the current timber growth, even though it is concerned with economic depreciation of immature forest (Vincent and Hartwick 1997). It includes the timber rent from the harvested mature timber at the optimal rotation age.

To calculate equations *(29)* and *(30)*, we need data on the per hectare timber rent of harvested timber at maturity, the age-class distribution of forest (area and volume), the optimal rotation age, and the social discount rate. The age-class distributions (area and volume per hectare) of timber productive forests by eight provinces and Yukon Territory (excluding Prince Edward Island, Manitoba, and the Northwest Territories) for 1970-91 are available from Canada's Forest Inventory 1991 (CanFI91) (Table 3.12). In the V-H approach, British Columbia (BC) is separately estimated in its economic depreciation from the rest of Canada (RC)[59] because BC's harvest volumes,[60] timber rents,[61] and growth patterns[62] are much higher than for the rest of

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[58] See Vincent and Hartwick (1997) for further discussion of the expression involving future price changes and harvesting levels.
[59] It excludes Prince Edward Island, Manitoba, and Northwest Territories since their age-class distribution data are not available.
[60] See Statistics Canada, Econnections, 1997.
[61] See Table 3.17, 3.18, and 3.19.
[62] See Table 3.12, Table A.I-1 and A.I-2, and Figure A.I-1 and A.I-2.

Table 3.12 Age-Class Distribution of Timber Productive Forests by Provinces

Province/Territory		Nonstocked	Stocking unproven	Stocked by age class 0	1-20	21-40	41-60	61-80	81-100	101-120	121-140	141-160	161+	Uneven	Unclass	Total
Newfoundland	Area	370.0	23.0	-	335.0	299.0	315.0	766.0	882.0	-	-	-	-	-	231.0	3,220.0
	Volume	.	...	...	14.9	39.6	79.3	106.8	112.8	...	...	...	...	...	57.4	83.6
Nova Scotia	Area	234.0	485.0	-	55.0	421.0	1,484.0	793.0	130.0	20.0	-	-	-	37.0	110.0	3,767.0
	Volume		...	-	10.5	31.2	90.1	11.7	96.3	75.6	...	...	...	51.9	84.7	85.6
P.E.I.	Area	-	33.0	-	-	-	-	-	-	-	-	-	-	-	245.0	278.0
	Volume		...	...	...		...	...			...	...	...		106.3	106.3
New Branswick	Area	66.0	41.0	273.0	899.0	408.0	1,283.0	1,452.0	933.0	364.0	145.0	68.0	11.0	10.0	-	5,954.0
	Volume	.	...	5.3	34.9	82.8	121.6	131.3	136.3	139.4	149.8	151.9	170.8	138.8	...	107.2
Quebec	Area	-	4,841.0	-	1,008.0	1,930.0	3,086.0	2,700.0	1,822.0	868.0	-	-	-	153.0	38,381.0	54,789.0
	Volume	.	...	...	25.4	71.4	106.6	128.6	141.3	124.5	...	...	..	122.1	80.4	86.3
Ontario	Area	-	3,167.0	1,243.0	1,521.0	4,135.0	7,968.0	7,459.0	4,990.0	3,741.0	3,007.0	810.0	245.0	6.0	3,911.0	42,202.0
	Volume	..	...	...	10.5	50.2	94.8	122.9	118.2	127.1	128.6	125.8	146.7	122.4	71.6	96.5
Manitoba	Area	-	1,788.0	-	-	-	-	-	-	-	-	-	-	-	13,452.0	15,239.0
	Volume		...	...	...	.	...	...		.	...	-	...	.	67.8	67.8
Saskatchewan	Area	-	1,394.0	-	341.0	1,010.0	1,557.0	1,065.0	1,246.0	545.0	213.0	26.0	1.0	-	5,237.0	12,633.0
	Volume	.	...	..	18.7	77.8	107.8	145.7	145.9	136.7	118.5	104.9	103.4	.	39.1	79.8
Alberta	Area	249.0	2,008.0	1.0	204.0	1,098.0	5,773.0	4,215.0	4,051.0	2,635.0	1,785.0	618.0	456.0	-	2,610.0	25,705.0
	Volume		...	8.4	16.7	55.8	74.9	122.8	193.5	208.8	208.3	210.1	195.6	...	54.0	131.4
B.C.	Area	4,351.0	8.0	-	1,684.0	2,567.0	3,886.0	4,735.0	4,890.0	5,589.0	3,887.0	15,013.0	4,933.0	-	196.0	51,739.0
	Volume		..		4.8	49.8	70.7	138.4	192.0	221.6	241.4	288.9	412.5	.	115.8	223.2
Labrador	Area	-	3,203.0	-	-	1.0	-	-	12.0	20.0	20.0	29.0	77.0	-	4,687.0	8,051.0
	Volume		...	..	-	-	91.9	91.9	118.4	123.3	123.3	114.5	109.8	..	57.4	59.2
Yukon	Area	188.0	1,632.0	-	15.0	71.0	87.0	241.0	884.0	834.0	159.0	50.0	13.0	-	3,296.0	7,470.0
	Volume		...	...	15.0	51.5	73.3	132.7	166.3	162.6	192.5	218.6	226.6	..	81.4	112.9
N.W.T.	Area	-	39.0	-	-	-	-	-	-	-	-	-	-	-	14,281.0	14,321.0
	Volume	.	...	...	...	...	...	...	..	...	...	...	...	...	33.2	33.2
Canada	**Area**	**5,458.0**	**18,662.0**	**1,518.0**	**6,062.0**	**11,939.0**	**25,440.0**	**23,426.0**	**19,838.0**	**14,617.0**	**9,217.0**	**16,615.0**	**5,736.0**	**206.0**	**86,638.0**	**245,370.0**
	Volume		...	**1.0**	**15.9**	**56.6**	**89.6**	**127.4**	**158.2**	**180.5**	**192.8**	**276.7**	**379.0**	**110.5**	**65.9**	**117.9**

Notes: Areas are measure in thousands of hectraes.
Volumes are measure in qubic meters per hectare.
- implies zero value. ... implies not applicable.
The 'unproven' column includes 15,000 ha with no stocking classification
Unproven' stocking is forestland that has had the tree cover removed or killed and where the subsequent degree of stocking has not been assessed. There is a lag time after disturbance before stocking can be established and recognized.
This is not dealt in area classification of Statistics Canada (1997).
Source: Canada's Forest Inventory 1991 (Lowe, Power, and Gray 1994).

Application of stocking factors to reassign areas of 'unproven' and 'unclassified' stocking by Canada

		Nonstocked	Stocking unproven	Stocked by age class 0	1-20	21-40	41-60	61-80	81-100	101-120	121-140	141-160	161+	Uneven	Unclass	Total
Before adjustment		5,458.0	18,662.0	1,518.0	6,062.0	11,939.0	25,440.0	23,426.0	19,838.0	14,617.0	9,217.0	16,615.0	5,736.0	206.0	86,638.0	245,370.0
Adjustment - a		└────	──┴──►	5,458.0		...	...	...	...	...	...	...	...	...	...	...
				60% ▼	40% ▼											
Adjustment - b		...	...	11,197.0	7,465.0	...	...	...	...	...	...	...	...	...	...	...
Canada	**Area**	...	...	**18,173.0**	**13,527.0**	**11,939.0**	**25,440.0**	**23,426.0**	**19,838.0**	**14,617.0**	**9,217.0**	**16,615.0**	**5,736.0**	**206.0**	**86,638.0**	**245,370.0**

Notes: For adjustemnt - a, nonstocked (including 'unproven' stocking) is allocated to age class 0.
For adjustment - b, the stocked portion of 'unproven' and 'unspecified' stocking is allocated to the youngest age class (1-20).
Areas are measure in thousands of hectraes.
Source: Appendix1, Table 16.5 from Canada's Forest Inventory 1991 (Lowe, Power, and Gray 1994)

Canada. In addition, because of these factors, it is expected that the optimal rotation ages would be different between BC and RC.[63]

The roundwood products price (per cubic meter) and the harvesting costs in the logging industry (per hectare) during the period 1970-93 are calculated from Statistics Canada, Catalogue. No.25-101 and 25-202 (Table 3.13 and 3.15 for BC and Table 3.14 and 3.16 for RC).

Based on the age-class volume information in Table 3.12, the yield functions of BC and RC, which provide the relationship between standing timber volume per hectare and age, are estimated as:

$$Y(t) = 3696.1*(1 - \exp(-0.001t)^{1.33} \qquad \text{(BC)}$$

$$Y(t) = 172.4*(1 - \exp(-0.02t)^{1.39} \qquad \text{(RC)}$$

which have logistic shapes (Figure A.I-1 for BC and Figure A.I-2 for RC). The average roundwood products[64] prices for 1970-93 were $46.7 per cubic meters (1986=100) in BC (Table 3.13) and $32.2 per cubic meters in RC (Table 3.14). The average of harvesting costs in the logging industry for 1970-93 were $7,917.2 per hectare in BC (Table 3.15) and $2,701.1 per hectare in RC (Table 3.16). The harvesting costs in the logging industry do not include regeneration costs. However, silviculture costs are also considered in the calculation of the optimal rotation age. The average silviculture costs for 1970-93 were $536.6 per hectare in BC and $727.1 per hectare in RC (Table A.I-1). A social discount rate (*r*) of 4 per cent is assumed reflecting the average provincial government real borrowing rate over the period since 1961. Under these assumptions, the optimal rotation ages with regeneration costs become 115 years in BC and 63 years in RC and the rotation ages without regeneration costs become 120 years in BC and 79 years in RC (Table A.I-2). (The calculation of the optimal rotation age is provided in Appendix I).

Consequently, economic depreciation of timber resources (D_t) is given as the sum of the per hectare economic depreciation of mature forest areas (A_T) and the per hectare appreciation of immature forest areas (A_t):

$$D_t = A_{T,BC}D_{T,BC} + \Sigma A_{t,BC}D_{t,BC} + A_{T,RC}D_{T,RC} + \Sigma A_{t,RC}D_{t,RC} \qquad (31)$$

[63] See Table A.I-4.
[64] Roundwood products include logs, bolts, pulpwood, posts, pilings, and other products still in the round in the subcategory called industrial roundwood and also include fuelwood (for industrial needs) and firewood (for household or recreational needs) (National Forestry Database Program).

Table 3.13 Roundwood Products Price (British Columbia)

Year	Value of shipments (Millions of current $)	Implicit PPI	($ (1986=100))	Volume (Cubic meters)	Price per volume ($ (1986=100))
	1)	2)	3)	4)	5)=3)/4)
1970	883.9	32.8	2,694,800,000	54,733,163	49.2
1971	926.0	33.9	2,731,600,000	56,551,000	48.3
1972	1,109.4	35.8	3,098,900,000	56,451,000	54.9
1973	1,588.1	39.0	4,072,100,000	70,137,000	58.1
1974	1,577.5	44.6	3,537,000,000	60,086,000	58.9
1975	1,314.3	49.0	2,682,200,000	50,078,000	53.6
1976	1,931.4	53.3	3,623,600,000	69,521,000	52.1
1977	2,095.2	56.6	3,716,000,000	69,971,000	53.1
1978	2,473.8	60.0	4,123,000,000	75,164,000	54.9
1979	2,376.6	66.0	3,600,900,000	76,195,000	47.3
1980	2,610.3	73.0	3,575,800,000	74,654,000	47.9
1981	2,190.5	80.9	2,707,700,000	60,780,000	44.5
1982	1,930.3	87.9	2,196,000,000	56,231,000	39.1
1983	2,591.8	92.3	2,808,000,000	71,443,000	39.3
1984	2,675.7	95.2	2,810,600,000	74,556,000	37.7
1985	2,737.0	97.7	2,801,400,000	76,868,000	36.4
1986	2,796.3	100.0	2,796,300,000	77,502,000	36.1
1987	3,907.3	104.7	3,731,900,000	90,591,000	41.2
1988	4,105.5	109.6	3,745,900,000	86,807,000	43.2
1989	4,351.7	114.9	3,787,400,000	87,414,000	43.3
1990	4,017.7	118.6	3,387,600,000	78,316,000	43.3
1991	3,848.5	121.9	3,157,100,000	74,706,000	42.3
1992	4,294.3	123.4	3,480,000,000	78,579,000	44.3
1993	4,976.4	124.7	3,990,700,000	78,004,000	51.2
Average					46.7

Source: Statistics Canada. Catalogue. No. 25-201 and 25-202; CANSIM Series P49000, D20556, and B3400; and Statistics Canada, Econnections, 1997.

Table 3.14 Roundwood Products Price (the Rest of Canada)

Year	Value of shipments (Millions of current $)	Implicit PPI	($ (1986=100))	Volume (Cubic meters)	Price per volume ($ (1986=100))
	1)	2)	3)	4)	5)=3)/4)
1970	735.7	32.8	2,243,000,000	66,702,407	33.6
1971	703.5	33.9	2,075,200,000	63,151,000	32.9
1972	763.2	35.8	2,131,800,000	67,679,000	31.5
1973	906.2	39.0	2,323,600,000	73,669,000	31.5
1974	1,155.1	44.6	2,589,900,000	77,843,000	33.3
1975	1,159.4	49.0	2,366,100,000	65,185,000	36.3
1976	1,281.6	53.3	2,404,500,000	69,605,000	34.5
1977	1,403.2	56.6	2,479,200,000	75,291,000	32.9
1978	1,572.7	60.0	2,621,200,000	80,731,000	32.5
1979	1,845.6	66.0	2,796,400,000	85,562,000	32.7
1980	1,949.0	73.0	2,669,900,000	80,726,000	33.1
1981	2,239.2	80.9	2,767,900,000	83,792,000	33.0
1982	2,064.4	87.9	2,348,600,000	70,785,000	33.2
1983	2,323.2	92.3	2,517,000,000	85,478,000	29.4
1984	2,688.7	95.2	2,824,300,000	92,946,000	30.4
1985	2,724.5	97.7	2,788,600,000	91,152,000	30.6
1986	2,979.2	100.0	2,979,200,000	86,506,000	34.4
1987	3,631.0	104.7	3,468,000,000	104,800,000	33.1
1988	3,956.4	109.6	3,609,900,000	103,445,000	34.9
1989	4,345.1	114.9	3,781,600,000	100,344,000	37.7
1990	4,096.1	118.6	3,453,700,000	88,650,000	39.0
1991	3,853.4	121.9	3,161,100,000	86,802,000	36.4
1992	4,064.0	123.4	3,293,400,000	91,609,000	36.0
1993	4,054.5	124.7	3,251,400,000	98,355,000	33.1
Average					32.2

Source: Statistics Canada. Catalogue. No. 25-201 and 25-202; CANSIM Series P49000, D20556, and B3400; and Statistics Canada, Econnections, 1997.

Table 3.15 Harvesting Cost in Logging Industry (British Columbia)

	(Millions of current $)						($ (1986=100))	(Hectares)	($ (1986=100))
Year	Value-added	Labor cost	Cost of fuel and electricity	Cost of materials and supplies	Total cost	Implicit PPI		Harvest (area)	Average cost per hectare
	1)	2)	3)	4)	5)=2)+3)+4)		5)'	6)	5)'/6)
1970	329.2	137.1	11	539.8	687.90	32.8	2,097,260,000	262,500	7,989.6
1971	351.1	150.4	12.3	561.8	724.50	33.9	2,137,170,000	270,300	7,906.7
1972	434.7	167.9	15.4	663.2	846.50	35.8	2,364,530,000	269,000	8,790.1
1973	596.0	236.5	20.1	1020.3	1,276.90	39.0	3,274,100,000	333,300	9,823.3
1974	586.7	253	24.7	1014.5	1,292.20	44.6	2,897,310,000	284,600	10,180.3
1975	449.2	220.1	20.1	841.6	1,081.80	49.0	2,207,760,000	236,400	9,339.1
1976	680.6	296.7	28.7	1264.5	1,589.90	53.3	2,982,930,000	326,500	9,136.1
1977	719.5	323.2	30.2	1361.8	1,715.20	56.6	3,030,390,000	327,300	9,258.8
1978	842.1	388.8	34.6	1636.9	2,060.30	60.0	3,433,830,000	350,200	9,805.3
1979	946.6	445.0	40.9	1466.6	1,952.50	66.0	2,958,330,000	353,700	8,364.0
1980	1,016.0	483.9	50.2	1565.5	2,099.60	73.0	2,876,160,000	345,200	8,331.9
1981	861.5	421.4	60.6	1221.7	1,703.70	80.9	2,105,930,000	280,000	7,521.2
1982	785.3	375.1	73.2	1022.3	1,470.60	87.9	1,673,040,000	258,000	6,484.7
1983	1,138.7	513.6	93.7	1381.8	1,989.10	92.3	2,155,040,000	326,400	6,602.5
1984	1,057.9	545.7	97.9	1527.1	2,170.70	95.2	2,280,150,000	338,900	6,728.1
1985	1,039.5	541.8	91.6	1603.7	2,237.10	97.7	2,289,760,000	348,000	6,579.8
1986	1,066.4	537.5	90.4	1632.7	2,260.60	100.0	2,260,600,000	349,400	6,469.9
1987	1,410.4	587.3	95.6	2053	2,735.90	104.7	2,613,090,000	406,700	6,425.1
1988	1,664.5	691.6	123.2	2335.7	3,150.50	109.6	2,874,540,000	388,000	7,408.6
1989	1,755.4	739.5	131.1	2481.2	3,351.80	114.9	2,917,150,000	389,100	7,497.2
1990	1,524.1	678.3	127.6	2343.6	3,149.50	118.6	2,655,560,000	328,200	8,091.3
1991	1,413.3	639.8	122.4	2257.8	3,020.00	121.9	2,477,440,000	381,900	6,487.1
1992	1,653.9	714.8	133.7	2522	3,370.50	123.4	2,731,360,000	387,200	7,054.1
1993	2,013.7	790.5	149.5	2847.8	3,787.80	124.7	3,037,530,000	392,500	7,738.9
Average									7,917.2

Note: Manufacturing Activity Only (not as Total Activity)
Source: Statisctics Canada. Catalogue. No. 25-201 and 25-202.
CANSIM Series P49000, D20556, and B3400.
Statistics Canada, Econnections, 1997.

Table 3.16 Harvesting Cost in Logging Industry (the Rest of Canada)

	(Millions of current $)						($ (1986=100))	(Hectares)	($ (1986=100))
Year	Value-added	Labor cost wages	Cost of fuel and electricity	Cost of materials and supplies	Total cost	Implicit PPI		Harvest (area)	Average cost per hectare
	1)	2)	3)	4)	5)=2)+3)+4)		5)'		5)'/6)
1970	353.8	207.7	18.1	359.2	585.0	32.8	1,783,540,000	659,200	2,705.6
1971	334.7	193.2	18	339.3	550.5	33.9	1,623,890,000	614,900	2,640.9
1972	379.6	214.2	21.4	332.5	568.1	35.8	1,586,870,000	650,800	2,438.3
1973	493.1	276.2	29.9	425.9	732.0	39.0	1,876,920,000	716,000	2,621.4
1974	634.1	348.1	43.7	570.7	962.5	44.6	2,158,070,000	755,600	2,856.1
1975	653.5	367.9	44.3	583.5	995.7	49.0	2,032,040,000	626,700	3,242.4
1976	649.1	342.1	42.2	587.8	972.1	53.3	1,823,830,000	669,600	2,723.8
1977	701.7	370.3	44	624.8	1,039.1	56.6	1,835,870,000	723,100	2,538.9
1978	786.7	419.3	50	745.9	1,215.2	60.0	2,025,330,000	779,100	2,599.6
1979	875.9	481.7	59.7	916.2	1,457.6	66.0	2,208,480,000	825,100	2,676.6
1980	911.1	481.0	70.8	1031.1	1,582.9	73.0	2,168,360,000	775,200	2,797.2
1981	995.5	522.9	98.2	1222.2	1,843.3	80.9	2,278,490,000	809,000	2,816.4
1982	830.3	422.8	105.6	1075.4	1,603.8	87.9	1,824,570,000	681,100	2,678.9
1983	972.6	499.0	106	1223.4	1,828.4	92.3	1,980,930,000	810,300	2,444.7
1984	1,114.1	554.2	117.2	1476.9	2,148.3	95.2	2,256,620,000	894,200	2,523.6
1985	1,127.7	558.2	127.4	1455	2,140.6	97.7	2,190,990,000	877,100	2,498.0
1986	1,193.9	587.1	129.9	1622.1	2,339.1	100.0	2,339,100,000	951,900	2,457.3
1987	1,271.9	597.5	134.1	1743.3	2,474.9	104.7	2,363,800,000	967,900	2,442.2
1988	1,689.2	730.6	160.5	2111.9	3,003.0	109.6	2,739,960,000	985,300	2,780.8
1989	1,875.9	817.3	250.3	2359.6	3,427.2	114.9	2,982,770,000	929,800	3,208.0
1990	1,653.1	745.8	155.4	2266.4	3,167.6	118.6	2,670,830,000	786,000	3,398.0
1991	1,483.6	695.9	143.9	2142.5	2,982.3	121.9	2,446,510,000	955,480	2,560.5
1992	1,582.8	748.4	151.1	2234.7	3,134.2	123.4	2,539,870,000	970,887	2,616.0
1993	1,591.2	739.5	153.8	2255.7	3,149.0	124.7	2,525,260,000	986,366	2,560.2
Average									**2,701.1**

Note: Manufacturing Activity Only (not as Total Activity)
Source: Statisctics Canada. Catalogue. No. 25-201 and 25-202.
CANSIM Series P49000, D20556, and B3400.
Statistics Canada, Econnections, 1997.

The sum in the term of immature forest is evaluated at t = 1,...., T-1 because t < T is assumed. Forest areas (A_t and A_T) by age-class for 1970-91 are estimated based on the 1991 age-class distribution from Canada's Forest Inventory 1991 (CanFI91) (Table 3.12) and the changes of timber stock areas for 1970-90 from Statistics Canada (1997) (Table A.II-1 for BC and Table A.II-3 for Canada).[65] Appendix II outlines the adjustment of the age-class distributions for BC and RC and show the estimated results (Table A.II-3 and Figure A.II-1 for BC and Table A.II-7 and Figure A.II-2 for RC).

Vincent and Hartwick (1997) state that A_T is the areas of mature forest that is harvested at the optimal rotation age (*T*) in a given period, and A_t is the areas of immature forest of age *t* that is left to grow. However, the calculated optimal rotation ages are not realistic. In Canada, current rotations are much longer than the estimated optimal rotations. There may be a number of reasons for this. First, residual stumpage values used to calculate the rotations are based on average costs, not marginal costs. Second, and perhaps more importantly, the calculated optimal rotation ages do not take into account the regulatory regimes that limit harvesting levels. Hence, in this analysis, other scenarios are considered. In scenario 1, all existing standing timber is harvested at the age of 161 years (T = 161), which is the oldest age-class in the age-class distribution data from CabFI91, and the capitalized forestland values are also calculated at the age of 161 years. In scenario 2 and 3, all standing timber is also harvested at the age of 161 years, but the capitalized land site values are calculated using the estimated optimal rotation ages. Only scenario 3's land site values and optimal rotation age are estimated with regeneration costs considered.

3.3.3.10 Results: V-H Approach

The results from the V-H approach are shown in Table 3.17 (scenario 1), 3.18 (scenario 2) and 3.19 (scenario 3). The final column in each scenario's table shows respective economic depreciation estimates of Canada's timber resources. The average economic depreciation of Canada's timber resources (as the sum of mature and immature forests) for 1970-90 were $26.5 million for scenario1, $68.9 million for scenario 2, and –$88.9 million for scenario 3.[66] In all cases, the overall pattern shows that Canada's timber resources were appreciating consistently before 1977/78 and depreciating consistently after the year 1982. Scenario 3 that incorporates the land values and the rotation age accounting for regeneration costs into the formula presents

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[65] As shown in Appendix II, the rest of Canada's forest areas by age-class are calculated by subtracting BC's from Canada's.

[66] Those averages are derived from excluding the extreme economic depreciation values in 1991 in each scenario. These values are affected by the extremely small area sizes in the simulated age-class distribution (RC's A_T in 1991).

Table 3.17 Economic Depreciation for Total Forest Industries (V-H) (Scenario 1)

Scenario 1: Assume the age of harvest (T) and the land value = 161.
(r=0.04)

British Columbia (BC)

Year	Timber rent per hectare T=161 ($ (1986=100))	Land value per hectare T=161	Economic depreciation t=0,......,160 and T=161 (Thousands $ (1986=100))		Economic depreciation t=0,......,160 and T=161 (Millions $ (1986=100))
	BC	BC	BC		BC
			A(t)D(t)	A(T)D(T)	A(t)D(t)+A(T)D(T)
	1)	2)	3t)	3T)	4)=3t)+3T)
1970	8,219.4	14.9	(3,340,923.1)	2,160,852.6	(1,180.1)
1971	7,995.5	14.5	(3,287,941.5)	2,166,268.7	(1,121.7)
1972	9,282.3	16.8	(3,860,256.1)	2,499,617.4	(1,360.6)
1973	9,290.7	16.8	(3,889,633.9)	3,100,523.6	(789.1)
1974	9,199.1	16.7	(3,895,188.3)	2,621,053.9	(1,274.1)
1975	8,293.8	15.0	(3,569,423.1)	1,962,805.8	(1,606.6)
1976	8,023.4	14.5	(3,481,993.2)	2,622,931.4	(859.1)
1977	8,225.1	14.9	(3,599,574.9)	2,695,015.5	(904.6)
1978	8,253.2	15.0	(3,636,173.3)	2,894,530.4	(741.6)
1979	7,194.4	13.0	(3,189,467.8)	2,547,962.3	(641.5)
1980	7,437.0	13.5	(3,321,343.1)	2,570,942.0	(750.4)
1981	7,145.1	13.0	(3,233,470.7)	2,003,946.6	(1,229.5)
1982	6,372.2	11.6	(2,927,852.2)	1,650,766.5	(1,277.1)
1983	6,337.0	11.5	(2,932,718.0)	2,071,682.2	(861.0)
1984	5,682.6	10.3	(2,653,355.3)	1,928,603.1	(724.8)
1985	5,418.2	9.8	(2,551,545.3)	1,889,214.2	(662.3)
1986	5,408.2	9.8	(2,567,657.6)	1,892,521.7	(675.1)
1987	7,136.9	12.9	(3,401,911.2)	2,907,652.0	(494.3)
1988	6,797.7	12.3	(3,258,008.8)	2,641,641.3	(616.4)
1989	6,766.8	12.3	(3,261,844.7)	2,637,404.4	(624.4)
1990	6,149.1	11.1	(2,996,313.6)	2,022,410.9	(973.9)
1991	7,425.6	13.5	...	...	...

the Rest of Canada (RC)

Year	Timber rent per hectare T=161 ($ (1986=100))	Land value per hectare T=161	Economic depreciation t=0,......,160 and T=161 (Thousands $ (1986=100))		Economic depreciation t=0,......,160 and T=161 (Millions $ (1986=100))
	RC	RC	RC		RC
			A(t)D(t)	A(t)D(T)	A(t)D(t)+A(T)D(T)
	5)	6)	7t)	7T)	8)=7t)+7T)
1970	3,025.7	5.5	(1,563,049.8)	1,836,018.9	273.0
1971	2,959.8	5.4	(1,515,853.3)	1,675,169.2	159.3
1972	2,930.2	5.3	(1,488,210.9)	1,759,414.7	271.2
1973	2,754.4	5.0	(1,368,484.4)	1,807,334.6	438.9
1974	2,814.5	5.1	(1,368,113.6)	1,946,422.1	578.3
1975	2,944.1	5.3	(1,407,489.9)	1,678,853.2	271.4
1976	3,164.0	5.7	(1,508,560.9)	1,953,379.4	444.8
1977	3,073.3	5.6	(1,437,057.5)	2,051,709.7	614.7
1978	2,934.3	5.3	(1,332,267.6)	2,101,510.0	769.2
1979	2,893.8	5.2	(1,272,557.1)	2,192,122.9	919.6
1980	2,839.8	5.1	(1,209,512.7)	2,022,855.7	813.3
1981	2,813.6	5.1	(1,151,189.9)	2,088,466.1	937.3
1982	2,976.2	5.4	(1,187,689.0)	1,865,808.1	678.1
1983	2,574.1	4.7	(984,461.2)	1,913,604.4	929.1
1984	2,655.4	4.8	(964,434.6)	2,175,835.3	1,211.4
1985	2,716.2	4.9	(937,160.8)	2,185,893.9	1,248.7
1986	3,412.5	6.2	(1,112,958.6)	3,011,783.6	1,898.8
1987	3,197.9	5.8	(963,469.1)	2,862,319.6	1,898.9
1988	3,166.9	5.7	(868,995.9)	2,871,525.6	2,002.5
1989	3,215.2	5.8	(797,791.9)	2,761,827.3	1,964.0
1990	3,242.1	5.9	(722,556.1)	2,323,769.1	1,601.2
1991	3,646.4	6.6	...	...	...

Canada (=BC + RC)

	($ (1986=100))		(Thousands $ (1986=100))		(Millions $ (1986=100))
Year	Timber rent per hectare T=161	Land value per hectare T=161	Economic depreciation t=0,.....,160 and T=161		Economic depreciation t=0,.....,160 and T=161
	Canada	Canada	Canada		Canada
			A(t)D(t)	A(T)D(T)	A(t)D(t)+A(T)D(T)
	8)=1)+5)	9)=2)+6)	10t)=3t)+7t)	10T)=3T)+7T)	11)=10t)+10T)
1970	11,245.1	14.9	(4,903,972.9)	3,996,871.5	(907.1)
1971	10,955.3	14.5	(4,803,794.8)	3,841,438.0	(962.4)
1972	12,212.5	16.8	(5,348,466.9)	4,259,032.1	(1,089.4)
1973	12,045.1	16.8	(5,258,118.3)	4,907,858.2	(350.2)
1974	12,013.6	16.7	(5,263,301.9)	4,567,476.0	(695.8)
1975	11,237.9	15.0	(4,976,913.1)	3,641,659.0	(1,335.2)
1976	11,187.4	14.5	(4,990,554.0)	4,576,310.7	(414.3)
1977	11,298.4	14.9	(5,036,632.4)	4,746,725.2	(289.9)
1978	11,187.5	15.0	(4,968,441.0)	4,996,040.4	27.6
1979	10,088.2	13.0	(4,462,024.9)	4,740,085.3	278.1
1980	10,276.8	13.5	(4,530,855.8)	4,593,797.7	62.9
1981	9,958.7	13.0	(4,384,660.6)	4,092,412.7	(292.2)
1982	9,348.4	11.6	(4,115,541.1)	3,516,574.6	(599.0)
1983	8,911.1	11.5	(3,917,179.2)	3,985,286.6	68.1
1984	8,338.0	10.3	(3,617,789.9)	4,104,438.4	486.6
1985	8,134.4	9.8	(3,488,706.0)	4,075,108.2	586.4
1986	8,820.7	9.8	(3,680,616.2)	4,904,305.4	1,223.7
1987	10,334.8	12.9	(4,365,380.3)	5,769,971.6	1,404.6
1988	9,964.6	12.3	(4,127,004.7)	5,513,167.0	1,386.1
1989	9,982.0	12.3	(4,059,636.6)	5,399,231.8	1,339.6
1990	9,391.1	11.1	(3,718,869.7)	4,346,180.0	627.3
1991	11,072.0	13.5	...	...	...
Average					26.5

Notes: Areas (A(t) and A(T)) are measure in thousands of hectares.
Average is taken by omitting economic depreciation in 1991.
... implies not applicable.

Table 3.18 Economic Depreciation for Total Forest Industries (V-H) (Scenario 2)

Scenario 2: Assume the age of harvest (T) = 161 and the land value at the optimal rotation age without accounting for regeneration costs.
(r=0.04)

British Columbia (BC)

	($ (1986=100))			(Thousands $ (1986=100))		(Millions $ (1986=100))
Year	Timber rent per hectare T=161	Timber rent per hectare T=115	Land value per hectare T=115	Economic depreciation t=0,.....,160 and T=161		Economic depreciation t=0,.....,160 and T=161
	BC	BC	BC	BC		BC
				A(t)D(t)	A(T)D(T)	A(t)D(t)+A(T)D(T)
	1)	2)	3)	4t)	4T)	5)=4t)+4T)
1970	8,219.4	2,717.0	30.2	(3,347,066.5)	2,160,693.4	(1,186.4)
1971	7,995.5	2,597.2	28.9	(3,287,991.1)	2,166,267.4	(1,121.7)
1972	9,282.3	3,147.3	35.0	(3,862,151.2)	2,499,568.2	(1,362.6)
1973	9,290.7	2,802.1	31.1	(3,891,769.9)	3,100,455.3	(791.3)
1974	9,199.1	2,620.4	29.1	(3,900,040.3)	2,620,923.0	(1,279.1)
1975	8,293.8	2,308.0	25.7	(3,569,534.2)	1,962,803.3	(1,606.7)
1976	8,023.4	2,198.3	24.4	(3,482,169.8)	2,622,926.0	(859.2)
1977	8,225.1	2,289.9	25.5	(3,600,196.7)	2,694,996.9	(905.2)
1978	8,253.2	2,122.9	23.6	(3,639,098.8)	2,894,437.1	(744.7)
1979	7,194.4	1,912.8	21.3	(3,193,572.1)	2,547,830.9	(645.7)
1980	7,437.0	2,083.9	23.2	(3,326,067.7)	2,570,795.5	(755.3)
1981	7,145.1	2,166.3	24.1	(3,238,083.5)	2,003,832.0	(1,234.3)
1982	6,372.2	2,007.7	22.3	(2,932,305.8)	1,650,665.9	(1,281.6)
1983	6,337.0	1,944.5	21.6	(2,938,312.0)	2,071,523.8	(866.8)
1984	5,682.6	1,469.6	16.3	(2,660,417.6)	1,928,397.4	(732.0)
1985	5,418.2	1,345.3	15.0	(2,558,414.6)	1,889,010.4	(669.4)
1986	5,408.2	1,376.0	15.3	(2,575,169.6)	1,892,299.8	(682.9)
1987	7,136.9	2,533.0	28.2	(3,409,614.5)	2,907,388.1	(502.2)
1988	6,797.7	1,975.1	22.0	(3,267,014.7)	2,641,348.7	(625.7)
1989	6,766.8	1,924.6	21.4	(3,272,776.0)	2,637,050.2	(635.7)
1990	6,149.1	1,314.9	14.6	(3,004,934.1)	2,022,177.7	(982.8)
1991	7,425.6	2,702.7	30.0	...	...	...

the Rest of Canada (RC)

	($ (1986=100))			(Thousands $ (1986=100))		(Millions $ (1986=100))
Year	Timber rent per hectare T=161	Timber rent per hectare T=63	Land value per hectare T=63	Economic depreciation t=0,.....,160 and T=161		Economic depreciation t=0,.....,160 and T=161
	RC	RC	RC	RC		RC
				A(t)D(t)	A(T)D(T)	A(t)D(t)+A(T)D(T)
	6)	7)	8)	9t)	9T)	10)=9t)+9T)
1970	3,025.7	941.5	86.9	(1,774,023.8)	1,999,483.1	225.5
1971	2,959.8	923.1	85.2	(1,692,932.2)	1,825,352.4	132.4
1972	2,930.2	977.9	90.3	(1,660,354.5)	1,911,497.3	251.1
1973	2,754.4	799.5	73.8	(1,544,436.2)	1,974,376.3	429.9
1974	2,814.5	752.4	69.4	(1,554,656.1)	2,132,445.6	577.8
1975	2,944.1	694.4	64.1	(1,609,899.7)	1,846,829.8	236.9
1976	3,164.0	1,022.9	94.4	(1,679,175.5)	2,125,467.5	446.3
1977	3,073.3	1,032.4	95.3	(1,595,780.7)	2,228,818.9	633.0
1978	2,934.3	921.8	85.1	(1,484,200.9)	2,289,429.6	805.2
1979	2,893.8	868.1	80.1	(1,428,351.4)	2,392,066.1	936.7
1980	2,839.8	789.9	72.9	(1,355,650.5)	2,214,130.3	858.5
1981	2,813.6	766.2	70.7	(1,292,547.2)	2,287,616.3	995.1
1982	2,976.2	919.7	84.9	(1,328,382.1)	2,033,757.7	705.4
1983	2,574.1	749.0	69.1	(1,110,300.5)	2,090,319.0	980.0
1984	2,655.4	772.0	71.3	(1,090,728.3)	2,376,569.2	1,285.8
1985	2,716.2	820.0	75.7	(1,057,169.1)	2,384,144.5	1,327.0
1986	3,412.5	1,277.9	118.0	(1,224,363.0)	3,255,855.0	2,031.5
1987	3,197.9	1,146.8	105.9	(1,065,170.7)	3,100,341.0	2,035.2
1988	3,166.9	1,004.0	92.7	(967,488.5)	3,127,157.8	2,159.7
1989	3,215.2	879.4	81.2	(897,501.4)	3,024,453.0	2,127.0
1990	3,242.1	827.4	76.4	(813,417.8)	2,551,110.5	1,737.7
1991	3,646.4	1,389.2	128.2	...	...	...

Canada (=BC + RC)

Year	Timber rent per hectare T=161 ($ (1986=100))	Timber rent per hectare T=115 and 63	Land value per hectare T=115 and 63	Economic depreciation t=0,......,160 and T=161 (Thousands $ (1986=100))		Economic depreciation t=0,......,160 and T=161 (Millions $ (1986=100))
	Canada	Canada	Canada	Canada		Canada
				A(t)D(t)	A(T)D(T)	A(t)D(t)+A(T)D(T)
	11)=1)+6)	12)=2)+7)	13)=3)+8)	12t)=4t)+9t)	12T)=4T)+9T)	13)=12t)+12T)
1970	11,245.1	3,658.4	117.1	(5,121,090.3)	4,160,176.5	(960.9)
1971	10,955.3	3,520.3	114.1	(4,980,923.3)	3,991,619.8	(989.3)
1972	12,212.5	4,125.2	125.3	(5,522,505.7)	4,411,065.5	(1,111.5)
1973	12,045.1	3,601.6	104.9	(5,436,206.1)	5,074,831.6	(361.4)
1974	12,013.6	3,372.8	98.6	(5,454,696.4)	4,753,368.6	(701.3)
1975	11,237.9	3,002.4	89.8	(5,179,433.9)	3,809,633.1	(1,369.8)
1976	11,187.4	3,221.2	118.9	(5,161,345.3)	4,748,393.6	(412.9)
1977	11,298.4	3,322.3	120.8	(5,195,977.4)	4,923,815.8	(272.2)
1978	11,187.5	3,044.7	108.7	(5,123,299.7)	5,183,866.8	60.5
1979	10,088.2	2,780.9	101.4	(4,621,923.4)	4,939,897.0	291.0
1980	10,276.8	2,873.9	96.1	(4,681,718.3)	4,784,925.8	103.2
1981	9,958.7	2,932.6	94.8	(4,530,630.7)	4,291,448.3	(239.2)
1982	9,348.4	2,927.4	107.2	(4,260,687.9)	3,684,423.6	(576.2)
1983	8,911.1	2,693.4	90.8	(4,048,612.5)	4,161,842.8	113.2
1984	8,338.0	2,241.6	87.6	(3,751,145.9)	4,304,966.6	553.8
1985	8,134.4	2,165.3	90.7	(3,615,583.7)	4,273,155.0	657.6
1986	8,820.7	2,653.9	133.3	(3,799,532.7)	5,148,154.8	1,348.6
1987	10,334.8	3,679.9	134.0	(4,474,785.2)	6,007,729.1	1,533.0
1988	9,964.6	2,979.1	114.6	(4,234,503.3)	5,768,506.5	1,534.0
1989	9,982.0	2,804.0	102.6	(4,170,277.3)	5,661,503.2	1,491.3
1990	9,391.1	2,142.3	91.0	(3,818,351.9)	4,573,288.2	754.9
1991	11,072.0	4,091.9	158.3	...	...	...
Average						68.9

Notes: Areas (A(t) and A(T)) are measure in thousands of hectares.
Average is taken by omitting economic depreciation in 1991.
... implies not applicable.

Table 3.19 Economic Depreciation for Total Forest Industries (V-H) (Scenario 3)

Scenario 3: Assume the age of harvest (T) and the land value at the optimal rotation age with accounting for regeneration costs.
(r=0.04)

British Columbia (BC)

Year	Timber rent per hectare T=161 ($ (1986=100))	Timber rent per hectare T=120	Land value per hectare T=120	Economic depreciation t=0,......,160 and T=161 (Thousands $ (1986=100))		Economic depreciation t=0,......,160 and T=161 (Millions $ (1986=100))
	BC	BC	BC	BC		BC
				A(t)D(t)	A(T)D(T)	A(t)D(t)+A(T)D(T)
	1)	2)	3)	4t)	4T)	5)=4t)+4T)
1970	8,219.4	3,300.0	(511.4)	(3,127,374.7)	2,160,721.7	(1,107.7)
1971	7,995.5	3,169.2	(512.6)	(3,071,571.4)	2,166,105.1	(1,055.8)
1972	9,282.3	3,797.4	(506.9)	(3,642,849.2)	2,499,521.5	(1,287.9)
1973	9,290.7	3,489.6	(509.7)	(3,669,590.8)	3,100,101.4	(748.3)
1974	9,199.1	3,317.5	(511.3)	(3,672,045.4)	2,620,582.4	(1,204.0)
1975	8,293.8	2,942.3	(514.7)	(3,341,856.4)	1,962,419.1	(1,506.1)
1976	8,023.4	2,815.5	(515.8)	(3,252,230.1)	2,622,385.2	(804.8)
1977	8,225.1	2,918.8	(514.9)	(3,368,129.6)	2,694,485.4	(849.0)
1978	8,253.2	2,772.5	(516.2)	(3,402,562.2)	2,893,801.0	(696.3)
1979	7,194.4	2,472.5	(519.0)	(2,954,038.0)	2,547,377.8	(596.2)
1980	7,437.0	2,651.2	(517.3)	(3,084,705.3)	2,570,448.5	(699.4)
1981	7,145.1	2,693.9	(517.0)	(2,994,097.4)	2,003,682.1	(1,170.7)
1982	6,372.2	2,470.2	(519.0)	(2,684,523.1)	1,650,599.8	(1,172.8)
1983	6,337.0	2,409.9	(519.5)	(2,687,405.8)	2,071,428.5	(791.2)
1984	5,682.6	1,916.0	(524.0)	(2,404,304.6)	1,928,124.1	(657.9)
1985	5,418.2	1,776.9	(525.3)	(2,299,994.3)	1,888,694.1	(597.9)
1986	5,408.2	1,803.2	(525.1)	(2,314,173.1)	1,892,031.0	(609.5)
1987	7,136.9	3,020.9	(514.0)	(3,151,205.9)	2,907,660.8	(462.4)
1988	6,797.7	2,486.1	(518.8)	(3,003,887.8)	2,641,205.5	(570.9)
1989	6,766.8	2,437.7	(519.3)	(3,006,076.7)	2,636,927.1	(577.9)
1990	6,149.1	1,827.2	(524.9)	(2,735,602.0)	2,021,672.3	(889.7)
1991	7,425.6	3,203.1	(512.3)	...	...	...

the Rest of Canada (RC)

Year	Timber rent per hectare T=161 ($ (1986=100))	Timber rent per hectare T=79	Land value per hectare T=79	Economic depreciation t=0,......,160 and T=161 (Thousands $ (1986=100))		Economic depreciation t=0,......,160 and T=161 (Millions $ (1986=100))
	RC	RC	RC	RC		RC
				A(t)D(t)	A(T)D(T)	A(t)D(t)+A(T)D(T)
	6)	7)	8)	9t)	9T)	10)=9t)+9T)
1970	3,025.7	1,502.6	(690.4)	(1,313,534.5)	2,000,998.7	207.1
1971	2,959.8	1,471.4	(691.9)	(1,264,552.5)	1,825,521.5	113.0
1972	2,930.2	1,503.5	(690.4)	(1,234,945.2)	1,911,762.0	202.9
1973	2,754.4	1,325.8	(698.8)	(1,115,091.8)	1,975,238.5	339.3
1974	2,814.5	1,307.5	(699.7)	(1,125,838.6)	2,133,783.5	457.3
1975	2,944.1	1,300.0	(700.0)	(1,179,852.7)	1,848,250.5	212.4
1976	3,164.0	1,599.3	(685.9)	(1,284,447.4)	2,125,470.9	353.1
1977	3,073.3	1,581.9	(686.7)	(1,211,141.9)	2,228,717.8	490.8
1978	2,934.3	1,463.6	(692.3)	(1,107,927.9)	2,289,429.0	614.7
1979	2,893.8	1,413.4	(694.7)	(1,054,534.8)	2,392,665.6	737.5
1980	2,839.8	1,341.8	(698.0)	(997,582.1)	2,214,359.1	650.4
1981	2,813.6	1,317.4	(699.2)	(946,813.6)	2,287,963.5	750.5
1982	2,976.2	1,473.3	(691.8)	(992,861.8)	2,034,045.4	544.7
1983	2,574.1	1,240.3	(702.8)	(781,309.8)	2,091,180.6	719.8
1984	2,655.4	1,279.0	(701.0)	(774,970.6)	2,377,819.2	952.4
1985	2,716.2	1,330.5	(698.6)	(758,896.8)	2,385,253.9	988.5
1986	3,412.5	1,852.5	(673.9)	(964,456.3)	3,254,959.8	1,597.6
1987	3,197.9	1,699.0	(681.2)	(820,466.8)	3,099,920.6	1,575.3
1988	3,166.9	1,586.3	(686.5)	(740,511.1)	3,127,112.1	1,669.3
1989	3,215.2	1,508.2	(690.2)	(685,596.2)	3,025,168.9	1,656.2
1990	3,242.1	1,477.4	(691.6)	(623,504.0)	2,551,595.8	1,356.4
1991	3,646.4	1,996.9	(667.1)	...	...	...

Canada (=BC + RC)

Year	Timber rent per hectare T=161 ($ (1986=100))	Timber rent per hectare T=120 and 79	Land value per hectare T=120 and 79	Economic depreciation t=0,.....,160 and T=161 (Thousands $ (1986=100))		Economic depreciation t=0,.....,160 and T=161 (Millions $ (1986=100))
	Canada	Canada	Canada	Canada		Canada
				A(t)D(t)	A(T)D(T)	A(t)D(t)+A(T)D(T)
	11)=1)+6)	12)=2)+7)	13)=3)+8)	12t)=4t)+9t)	12T)=4T)+9T)	13)=12t)+12T)
1970	11,245.1	4,802.6	(1,201.9)	(4,440,909.2)	4,161,720.4	(900.6)
1971	10,955.3	4,640.6	(1,204.5)	(4,336,123.9)	3,991,626.6	(942.8)
1972	12,212.5	5,300.9	(1,197.3)	(4,877,794.4)	4,411,283.5	(1,085.0)
1973	12,045.1	4,815.4	(1,208.5)	(4,784,682.6)	5,075,340.0	(409.0)
1974	12,013.6	4,625.0	(1,210.9)	(4,797,884.0)	4,754,366.0	(746.7)
1975	11,237.9	4,242.3	(1,214.7)	(4,521,709.2)	3,810,669.6	(1,293.7)
1976	11,187.4	4,414.8	(1,201.7)	(4,536,677.5)	4,747,856.1	(451.7)
1977	11,298.4	4,500.6	(1,201.6)	(4,579,271.5)	4,923,203.2	(358.2)
1978	11,187.5	4,236.1	(1,208.5)	(4,510,490.1)	5,183,230.0	(81.6)
1979	10,088.2	3,885.9	(1,213.6)	(4,008,572.8)	4,940,043.4	141.3
1980	10,276.8	3,992.9	(1,215.4)	(4,082,287.4)	4,784,807.6	(49.0)
1981	9,958.7	4,011.3	(1,216.1)	(3,940,911.0)	4,291,645.5	(420.2)
1982	9,348.4	3,943.5	(1,210.8)	(3,677,384.9)	3,684,645.2	(628.1)
1983	8,911.1	3,650.2	(1,222.4)	(3,468,715.6)	4,162,609.1	(71.4)
1984	8,338.0	3,195.0	(1,225.0)	(3,179,275.1)	4,305,943.3	294.5
1985	8,134.4	3,107.4	(1,223.9)	(3,058,891.2)	4,273,948.1	390.6
1986	8,820.7	3,655.8	(1,199.0)	(3,278,629.4)	5,146,990.8	988.1
1987	10,334.8	4,719.9	(1,195.1)	(3,971,672.6)	6,007,581.4	1,112.9
1988	9,964.6	4,072.4	(1,205.3)	(3,744,399.0)	5,768,317.6	1,098.4
1989	9,982.0	3,945.9	(1,209.5)	(3,691,672.9)	5,662,096.0	1,078.3
1990	9,391.1	3,304.6	(1,216.5)	(3,359,106.0)	4,573,268.0	466.7
1991	11,072.0	5,200.0	(1,179.4)	...	...	...
Average						(88.9)

Notes: Areas (A(t) and A(T)) are measure in thousands of hectares.
Average is taken by omitting economic depreciation in 1991.
... implies not applicable.

consistently smaller numbers than scenario 1 and 2 that do not account for regeneration costs during the period.

Table 3.20 and Figure 3.8 compare economic depreciation of timber resources using the V-H approach with other imputed values, such as Gravel's (1986 = 100), NP(1), and NP(2). Other estimations clearly tend to overstate the economic depreciation values depreciation because the procedure omits the increasing capitalized value of immature forests. This is consistent with the case study results in Malaysia by Vincent and Hartwick (1997) and in South Africa by Hassan (2000). Both studies suggest that the net price approach (as the simple product of net price times the changes in timber volume) clearly overstates economic depreciation.

The V-H approach may indeed be a more accurate method for imputing economic depreciation of timber stocks than the net price approach, such as NP(1) and NP(2) (Hassan 2000). However, the V-H approach is considerably more complicated than the net price approach. Furthermore, it is generally difficult to obtain the precise data on the age-class distribution, which is necessary information to calculate the V-H approach. In addition, the extra effort of applying the V-H approach may not be worth it if the values derived are not significantly different from the generated values using the standard net price approach (Vincent and Hartwick 1997).

3.4 Estimating Weak Sustainability in Canada's Forest Sector

In this section, weak sustainability measures are calculated for the entire forest sector based on the estimated economic depreciation using both NP(2) and the V-H method. Weak sustainability measures are represented by both adjusted forest sector NDP (equivalent to environmentally adjusted national accounts) and net investment (equivalent to the net savings approach). The operative constraint in weak sustainability is non-declining overall stock of capital under the assumption of unlimited substitutability between man-made capital and natural capital. If an economy's overall stocks of capital fall, then the income ability of future generations to meet their needs is reduced. On the other hand, if the stocks of natural capital are exploited to increase the stock of man-made capital, then income ability of future generations can be maintained.

Recall that the weak sustainability concept does not require that specific components of natural capital are sustained. Our measures are limited to Canada's forest sector. It is important to note that even if Canada's forest sector's economic contribution is unsustainable by our weak sustainability indicators, it does not necessarily imply that overall Canada's economy is also

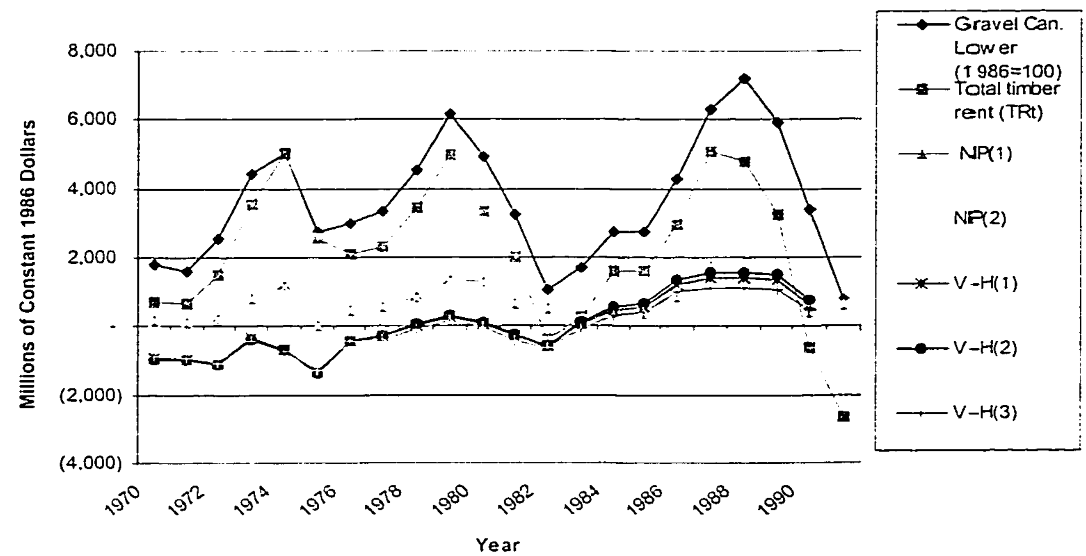
Table 3.20 Comparative Studies of Economic Depreciation in Canada's Forest Sector (C)

(Millions $ (1986=100))

Year	Gravel Canada (Lower bound)	Gravel Canada (Upper bound)	TRt	NP(1)	NP(2)	V-H scenario1	scenario2	scenario3
1970	1,793.0	2,333.2	719.4	151.2	149.7	(907.1)	(960.9)	(900.6)
1971	1,623.3	2,204.4	667.6	137.4	136.0	(962.4)	(989.3)	(942.8)
1972	2,546.1	3,161.5	1,514.2	224.4	222.2	(1,089.4)	(1,111.5)	(1,085.0)
1973	4,423.6	5,041.3	3,527.3	793.7	785.8	(350.2)	(361.4)	(409.0)
1974	5,014.8	5,622.2	5,020.5	1,183.9	1,172.1	(695.8)	(701.3)	(746.7)
1975	2,758.6	3,430.0	2,525.5	16.7	16.5	(1,335.2)	(1,369.8)	(1,293.7)
1976	2,992.1	3,677.1	2,086.9	457.1	452.5	(414.3)	(412.9)	(451.7)
1977	3,342.6	4,039.2	2,275.2	549.1	543.6	(289.9)	(272.2)	(358.2)
1978	4,530.2	5,233.2	,449.2	840.7	832.3	27.6	60.5	(81.6)
1979	6,171.7	6,861.8	4,962.4	1,338.1	1,324.7	278.1	291.0	141.3
1980	4,939.6	5,633.0	3,362.3	1,286.0	1,273.1	62.9	103.2	(49.0)
1981	3,228.4	3,937.1	1,986.5	667.6	661.0	(292.2)	(239.2)	(420.2)
1982	1,067.8	1,827.0	(376.2)	517.5	512.3	(599.0)	(576.2)	(628.1)
1983	1,712.5	2,506.4	257.6	67.7	67.0	68.1	113.2	(71.4)
1984	2,734.9	3,505.8	1,612.2	421.0	416.8	486.6	553.8	294.5
1985	2,758.8	3,518.1	1,605.4	383.9	380.1	586.4	657.6	390.6
1986	4,276.1	5,023.4	2,942.7	844.2	835.8	1,223.7	1,348.6	988.1
1987	6,330.9	7,069.4	5,065.7	1,751.7	1,734.2	1,404.6	1,533.0	1,112.9
1988	7,205.5	7,959.6	4,773.1	1,621.2	1,605.0	1,386.1	1,534.0	1,098.4
1989	5,917.5	6,721.0	3,247.5	1,625.9	1,609.6	1,339.6	1,491.3	1,078.3
1990	3,376.2	4,298.6	(632.7)	426.	422.2	627.3	754.9	466.7
1991	784.4	1,781.1	(2,663.0)	614.8	608.7	...	...	...
Average	3,614.9	4,335.6	2,178.6	723.6	716.4	26.5	68.9	(88.9)

Note: ... implies not applicable.

Figure 3.8 Comparative Studies of Economic Depreciation in Canada's Forest Sector (C): 1970-91



unsustainable. If sufficient investment occurs in other sectors, then overall net investment would be positive and overall NDP could rise (Vincent and Hartwick 1997).

3.4.1 Adjusted NDP of Canada's Forest Sector

We defined the adjusted forest sector NDP (or timber resource accounts) as:

Adjusted forest sector NDP = conventional forest sector GDP – depreciation of man-made capital in forest sector – depreciation of timber stock

This timber account assigns values to wood removed from Canada's forests. Table 3.21 and Figure 3.9 show the comparisons between the conventional domestic products (GDP and NDP) of Canada's forest industries and adjusted forest NDP. Column 2) of the table, the conventional net domestic products of forest industries, is obtained by subtracting man-made capital depreciation from the gross domestic products. The data for both the gross and net domestic product of Canada's are available from CANSIM Series I34003, I34116, and I34118, Statistics Canada, Input-Output Division.

Figure 3.9 Adjusted NDP of Total Forest Industries: 1970-93

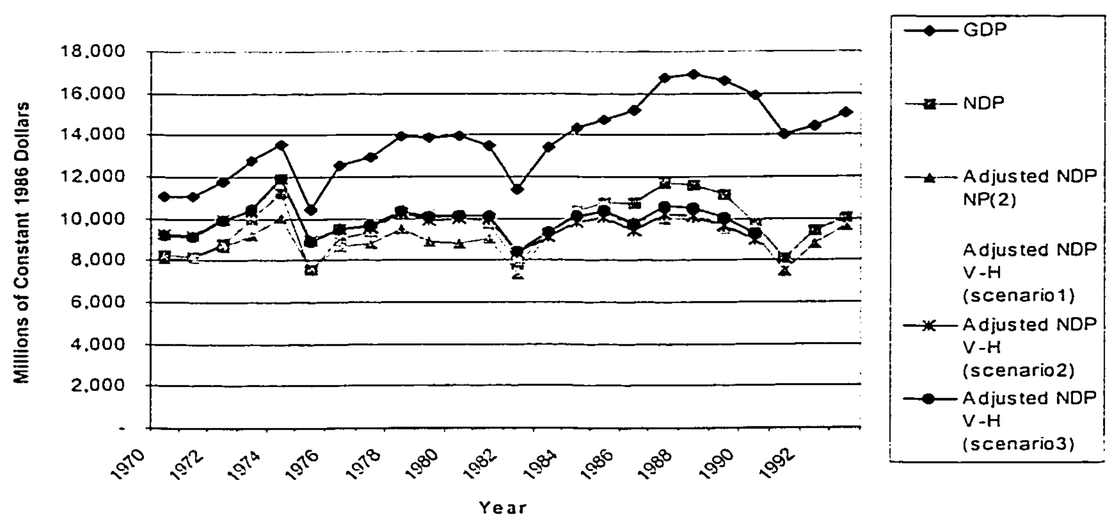


Table 3.21 Adjusted NDP of Total Forest Industries

(Millions $ (1986=100))

Year	GDP of total Forest industries	NDP of total forest industries	Economic depreciation				Adjusted NDP				Economic depreciation/NDP			
			NP(2)	V-H			NP(2)	V-H			NP(2)	V-H		
				Scenario 1	Scenario 2	Scenario 3		Scenario 1	Scenario 2	Scenario 3		Scenario 1	Scenario 2	Scenario 3
	1)	2)	3)	4)	5)	6)	7)=2)-3)	8)=2)-4)	9)=2)-5)	10)=2)-6)	11)=3)/2)	12)=4)/2)	13)=5)/2)	14=6)/2)
1970	11,090.1	8,275.0	149.7	(907.1)	(960.9)	(900.6)	8,125.3	9,182.1	9,235.9	9,175.6	0.018	(0.110)	(0.116)	(0.109)
1971	11,069.4	8,204.8	136.0	(962.4)	(989.3)	(942.8)	8,068.8	9,167.2	9,194.1	9,147.6	0.017	(0.117)	(0.121)	(0.115)
1972	11,787.5	8,843.3	222.2	(1,089.4)	(1,111.5)	(1,085.0)	8,621.1	9,932.7	9,954.8	9,928.3	0.025	(0.123)	(0.126)	(0.123)
1973	12,808.0	10,002.9	785.8	(350.2)	(361.4)	(409.0)	9,217.1	10,353.1	10,364.3	10,411.9	0.079	(0.035)	(0.036)	(0.041)
1974	13,554.4	11,198.1	1,172.1	(695.8)	(701.3)	(746.7)	10,026.0	11,893.9	11,899.4	11,944.8	0.105	(0.062)	(0.063)	(0.067)
1975	10,476.0	7,566.4	16.5	(1,335.2)	(1,369.8)	(1,293.7)	7,549.9	8,901.6	8,936.2	8,860.1	0.002	(0.176)	(0.181)	(0.171)
1976	12,560.2	9,071.5	452.5	(414.3)	(412.9)	(451.7)	8,619.0	9,485.8	9,484.4	9,523.2	0.050	(0.046)	(0.046)	(0.050)
1977	12,971.9	9,337.0	543.6	(289.9)	(272.2)	(358.2)	8,793.4	9,626.9	9,609.2	9,695.2	0.058	(0.031)	(0.029)	(0.038)
1978	13,966.5	10,312.4	832.3	27.6	60.5	(81.6)	9,480.1	10,284.8	10,251.9	10,394.0	0.081	0.003	0.006	(0.008)
1979	13,864.6	10,209.8	1,324.7	278.1	291.0	141.3	8,885.1	9,931.7	9,918.8	10,068.5	0.130	0.027	0.029	0.014
1980	13,977.3	10,096.5	1,273.1	62.9	103.2	(49.0)	8,823.4	10,033.6	9,993.3	10,145.5	0.126	0.006	0.010	(0.005)
1981	13,470.5	9,704.3	661.0	(292.2)	(239.2)	(420.2)	9,043.3	9,996.5	9,943.5	10,124.5	0.068	(0.030)	(0.025)	(0.043)
1982	11,354.1	7,798.1	512.3	(599.0)	(576.2)	(628.1)	7,285.8	8,397.1	8,374.3	8,426.2	0.066	(0.077)	(0.074)	(0.081)
1983	13,391.5	9,242.6	67.0	68.1	113.2	(71.4)	9,175.6	9,174.5	9,129.4	9,314.0	0.007	0.007	0.012	(0.008)
1984	14,367.9	10,390.2	416.8	486.6	553.8	294.5	9,973.5	9,903.6	9,836.4	10,095.7	0.040	0.047	0.053	0.028
1985	14,761.4	10,725.6	380.1	586.4	657.6	390.6	10,345.5	10,139.2	10,068.0	10,335.0	0.035	0.055	0.061	0.036
1986	15,224.1	10,766.1	835.8	1,223.7	1,348.6	988.1	9,930.3	9,542.4	9,417.5	9,778.0	0.078	0.114	0.125	0.092
1987	16,721.7	11,712.3	1,734.2	1,404.6	1,533.0	1,112.9	9,978.1	10,307.7	10,179.3	10,599.4	0.148	0.120	0.131	0.095
1988	16,889.3	11,646.2	1,605.0	1,386.1	1,534.0	1,098.4	10,041.2	10,260.1	10,112.2	10,547.8	0.138	0.119	0.132	0.094
1989	16,587.0	11,136.8	1,609.6	1,339.6	1,491.3	1,078.3	9,527.2	9,797.2	9,645.5	10,058.5	0.145	0.120	0.134	0.097
1990	15,917.3	9,702.4	422.2	627.3	754.9	466.7	9,280.2	9,075.1	8,947.5	9,235.7	0.044	0.065	0.078	0.048
1991	14,002.0	8,105.1	608.7	...	...	...	7,496.4	...	...	...	0.075	...	...	...
1992	14,378.3	9,434.5	612.9				8,821.7				0.065			
1993	15,051.9	10,037.3	386.9				9,650.4				0.039			
Ave.											0.070	-0.001	0.003	-0.012

Notes: ... implies not applicable.
Source: CANSIM Series I34003, I34103, I34303, I34116, and I34118.

Adjusted forest sector NDP using both NP(2) and the V-H approach were very close to the conventional forest sector NDP during most periods of 1970-93 (Figure 3.9). NP(2)-adjusted NDP is consistently smaller than the conventional forest sector NDP during the period. The V-H approach-adjusted NDP exceeded the conventional forest sector NDP in most years in the 1970s and in 1982/83 because the V-H calculations showed that Canada's forests were appreciating during those times, while the NP(2) estimations did not.

Table 3.21 also shows the ratios of economic depreciation to the conventional forest sector NDP (column 11), 12), 13), and 14)). The average ratio by NP(2) was 7.0 per cent. The average ratio for the V-H approach varies from –1.2 per cent of scenario 3 to 0.3 per cent of scenario 2. Scenario 2 presents the widest range of the ratio from –18.1 per cent (1975) to 13.4 per cent (1989). However, in either approach, it indicates that economic depreciation of Canada's forest sector was relatively small in proportion to the conventional forest sector NDP. The ratios of economic depreciation using NP(2) to the forest sector NDP slightly increased from the average 5.6 per cent in the 1970s to the average 7.7 per cent in the 1980s and 1990s. The ratios of economic depreciation using the V-H approach also increased from the average –6.7 per cent in the 1970s to 5.3 per cent in the 1980s (scenario 1), from –6.8 per cent in the 1970s to 5.8 per cent in the 1980s (scenario 2), and from –7.1 per cent in the 1970s to 3.2 per cent in the 1980s (scenario 3).

For the adjusted NDP measure, sustainability would be indicated by upward trends in adjusted forest sector NDP. As stated by Bartelmus (1994), this upward trend allows for depletion of timber resources and takes into account that past trends of depletion can be offset or mitigated by technological change, substitution, and changes in consumption patterns. However, in Figure 3.9, the trends are not visibly clear. NP(2) and scenario 3-adjusted NDP measure might demonstrate slight upward trends over the period. Although it is very difficult to conclude, adjusted forest sector NDP might narrowly indicate sustainability of Canada's forest sector.

3.4.2 Net Investment for Canada's Forest Sector

Another way of measuring sustainability of Canada's forest sector is to use net investment after taking into account depreciation of man-made capital and timber resources. This indicator is equivalent to the net savings measure of weak sustainability. The weak sustainability test of net investment (NI) associated with only forest manufacturing activities is defined as:

$$NI_{timber} = I_{timber} - \delta K_{m,\ timber} - \delta K_{n,\ timber}$$

where I_{timber} = investment in forest sector; $\delta K_{m,\ timber}$ = estimated value of depreciation of man-made capital in forest sector; and $\delta K_{n,\ timber}$ = estimated value of depreciation of timber resources.

Net investment can range from negative through zero to positive values. If net investment is either positive or at least zero every year, then it is considered that Canada's forest sector is on a sustainable path. On the other hand, a sustained negative net investment indicates that overall capital stock in Canada's forest sector is declining.

Table 3.22 shows net investment adjusted by economic depreciation using NP(2) and the V-H approach in Canada's forest sector for 1970-93. The conventional forest sector net investment (column 1), which is adjusted only by man-made capital) is obtained from the annual change of net capital stock. Therefore, the data are easily available from CANSIM Series D990389, D991037, and D991109, Statistics Canada, Investment and Capital Stock division, which were used in the calculations of the total timber rent in Section 3.3.3.2. All figures are shown in constant 1986 dollars using the Canadian GDP implicit price (Appendix Table A.III-2).

We find that economic depreciation using NP(2) surpassed forest sector investment in most years. Net investment in Canada's forest sector was negative in 17 years during the period 1970-93. On the other hand, the V-H approach-adjusted net investment shows negative net investment in some years in the 1970s and mid 1980s. In Figure 3.10, NP(2)-adjusted net investment shows sustained negative investment and the V-H approach-adjusted net investment fluctuates between positive and negative values. However, in both cases the overall pattern shows Canada's forest sector moved towards unsustainability over the period.

Although it is also difficult to make a firm conclusion, the evidence derived from the net investment measure seems to indicate that production from Canada's forest sector was unsustainable over the period of 1970-93. Thus, insufficient funds were reinvested in Canada's forest sector to offset depreciation of man-made capital and timber resources and the overall capital stock declined over the period.

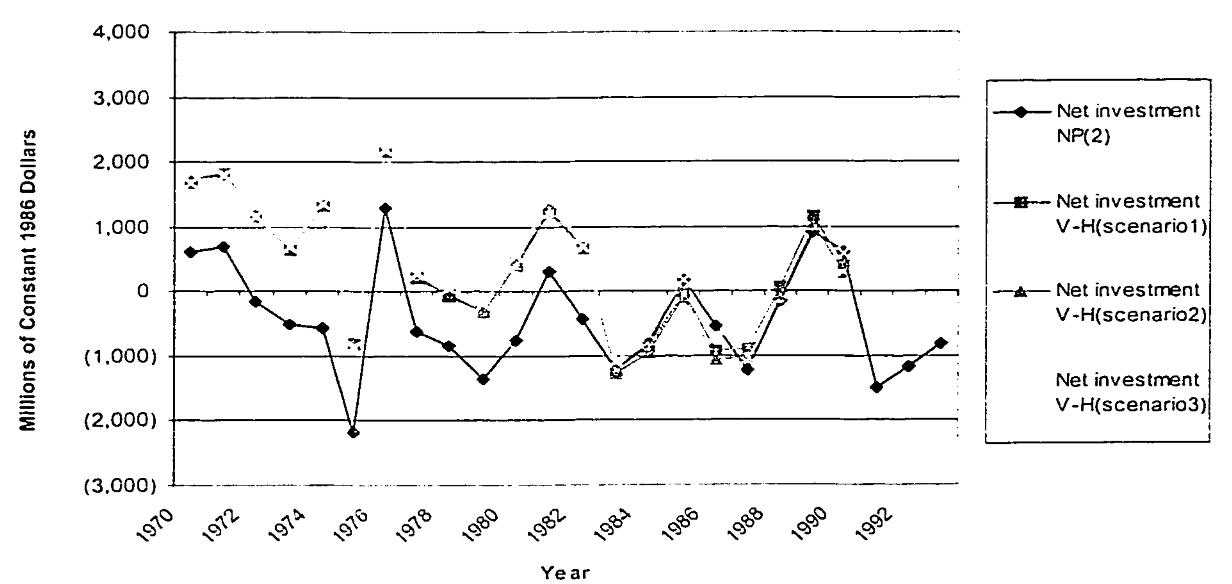
Table 3.22 Net investment for Total Forest Industries

(Millions $(1986=100))

Year	Investment	Economic depreciation				Net investment			
		NP(2)	V-H			NP(2)	V-H		
			Scenario 1	Scenario 2	Scenario 3		Scenario 1	Scenario 2	Scenario 3
	1)	2)	3)	4)	5)	6)=1)-2)	7)=1)-3)	8)=1)-4)	9)=1)-5)
1970	772.3	149.7	(907.1)	(960.9)	(900.6)	622.6	1,679.4	1,733.2	1,672.9
1971	838.1	136.0	(962.4)	(989.3)	(942.8)	702.1	1,800.5	1,827.4	1,780.9
1972	65.3	222.2	(1,089.4)	(1,111.5)	(1,085.0)	(156.8)	1,154.7	1,176.8	1,150.3
1973	274.6	785.8	(350.2)	(361.4)	(409.0)	(511.2)	624.8	636.0	683.6
1974	611.3	1,172.1	(695.8)	(701.3)	(746.7)	(560.8)	1,307.1	1,312.6	1,358.0
1975	(2,153.6)	16.5	(1,335.2)	(1,369.8)	(1,293.7)	(2,170.2)	(818.4)	(783.8)	(859.9)
1976	1,741.4	452.5	(414.3)	(412.9)	(451.7)	1,288.9	2,155.7	2,154.3	2,193.1
1977	(66.6)	543.6	(289.9)	(272.2)	(358.2)	(610.2)	223.3	205.6	291.6
1978	(7.5)	832.3	27.6	60.5	(81.6)	(839.8)	(35.1)	(68.0)	74.1
1979	(34.1)	1,324.7	278.1	291.0	141.3	(1,358.8)	(312.2)	(325.1)	(175.4)
1980	503.6	1,273.1	62.9	103.2	(49.0)	(769.6)	440.7	400.4	552.6
1981	971.0	661.0	(292.2)	(239.2)	(420.2)	310.0	1,263.2	1,210.2	1,391.2
1982	75.5	512.3	(599.0)	(576.2)	(628.1)	(436.8)	674.5	651.7	703.6
1983	(1,168.0)	67.0	68.1	113.2	(71.4)	(1,235.0)	(1,236.1)	(1,281.2)	(1,096.6)
1984	(386.5)	416.8	486.6	553.8	294.5	(803.3)	(873.1)	(940.3)	(681.0)
1985	557.6	380.1	586.4	657.6	390.6	177.5	(28.8)	(100.0)	167.0
1986	289.1	835.8	1,223.7	1,348.6	988.1	(546.7)	(934.6)	(1,059.5)	(699.0)
1987	513.6	1,734.2	1,404.6	1,533.0	1,112.9	(1,220.6)	(891.0)	(1,019.4)	(599.3)
1988	1,437.4	1,605.0	1,386.1	1,534.0	1,098.4	(167.7)	51.3	(96.6)	339.0
1989	2,509.1	1,609.6	1,339.6	1,491.3	1,078.3	899.5	1,169.5	1,017.8	1,430.8
1990	1,042.7	422.2	627.3	754.9	466.7	620.5	415.4	287.8	576.0
1991	(883.8)	608.7	...	...	...	(1,492.5)	...	...	...
1992	(548.7)	612.9				(1,161.6)			
1993	(427.3)	386.9				(814.2)			

Notes: ... implies not applicable.
Source: CANSIM Series D990389, D991037, and D991109.

Figure 3.10 Net Investment for Total Forest Industries: 1970-93



Chapter 4 Conclusion and Future Research

4.1 Summary and Conclusions

How do we properly include forest resource rents in environmental and natural resource accounts? With increasing public concerns over sustainable development, the issue is one of the most important challenges to be investigated in economics. Discussion and analysis of valuation methodologies and their application has evolved gradually over the past ten years. However, few studies have been conducted on the subject of natural capital depreciation of Canada's forest resources, in particular at the national level. Hence, it is hoped that this study will generate more interest in the practical problems involved in valuation method and policy implications with respect to Canada's forest resources.

This study proposed two weak sustainability indicators to measure sustainability of Canada's forest sector. Adjusted NDP and net investment measures were established based on the concepts of weak sustainability discussed in Chapter 2. Strong sustainability indicators were not used because they do not provide the explicit baselines and norms of ecological criticality and the spatial and temporal scale levels. Without a rigorous theoretical framework and common numeraire to measure sustainability unlike weak sustainability indicators, strong sustainability indicators are difficult to implement in a consistent measure. The operative definition of weak sustainability is non-declining overall stock of capital under the assumption of unlimited substitutability between man-made capital and natural capital. Hence, the weak sustainability criterion requires enough saving and investment to cancel out natural resource depletion and environmental degradation.

In this study, economic depreciation in Canada's forest sector during the period 1970-93 was calculated using two alternative net price approaches: the NP(1) and the NP(2), as well as the Vincent-Hartwick (V-H) approach: scenario 1, 2, and 3. The net price approaches incorporate changes of timber stock due to not only gross annual depletion but also regeneration. In particular, NP(2) is expressed as the correct version of taking into account current annual increment (g_t) related to the previous year's timber stock size (S_{t-1}), that is the growth stock effect. The empirical analysis demonstrated that economic depreciation generated by Canada's forest sector was the average of $705.4 million for the NP(1) and $698.4 million for the NP(2) during the period 1970-93. The results showed that results using NP(2) were slightly smaller than NP(1)'s because of negative growth stock effect (the opening timber stock has been declining as in Table 3.8). NP(1) and NP(2) estimation also indicated that the total timber rents, as well as Gravel's estimation overstated economic depreciation values using NP(1) and NP(2). This is because the total timber rent and Gravel's estimation are based on only gross annual depletion, which is timber harvesting and natural losses.

The V-H approach incorporates the age effect (remaining time in years to maturity) in timber resources and the age-class distribution of the timber stocks in the economic depreciation calculation. Separate equations were specified for mature forests and immature forests. This is because the expression of the net price approach is valid only if newly regenerated timber can be harvested immediately (Vincent 2000). The V-H approach involved three scenarios. Scenario 1 assumed that all standing timber is harvested at the age of 161 years (T = 161), which is the oldest age-class in the age-class distribution data from CabFI91, and the capitalized land values are also calculated at the age of 161 years. Scenario 2 and 3 assumed that all standing timber is also harvested at the age of 161 years, but the capitalized land site values are calculated using the estimated optimal rotation ages. Only scenario 3 took into account the land site values and optimal rotation age with regeneration cost consideration.

The average economic depreciation of Canada's timber resources (as the sum of mature and immature forests) for 1970-90 were $26.5 million for scenario1, $68.9 million for scenario 2, and –$88.9 million for scenario 3. In all cases, the overall pattern showed that Canada's timber resources were appreciating consistently before 1977/78 and depreciating consistently after the year 1982. The estimated results using the V-H approach also showed that economic depreciation calculation using other methods (even including the net price approach) significantly overstate the values since they fail to reflect the increasing capitalized value of immature forest.

We measured sustainability of Canada's forest sector based on the estimated results of economic depreciation using both NP(2) and the V-H approach. Adjusted forest sector NDP measure showed that Canada's forest sector was narrowly sustainable with slight upward trends over the period 1970-91. The average ratio to the conventional forest sector NDP using NP(2) was 7.0 per cent. The average ratio using the V-H approach varies from –1.2 per cent of scenario 3 to 0.3 per cent of scenario 2. Scenario 2 presents the widest rage of the ratio from –18.1 per cent (1975) to 13.4 per cent (1989). However, in either approach, economic depreciation of Canada's forest sector was relatively small in proportion to the conventional forest sector NDP.

The net investment measure showed more complicated results of sustainability of Canada's forest sector. The NP(2) adjusted-net investment was negative in most years. Net investment in Canada's forest sector was negative in 17 of the 24 years during the period 1970-93. On the other hand, the V-H approach-adjusted net investment shows negative net investment in 8 years in scenario 1, 9 years in scenario 2, and 6 years in scenario 3 in the 1970s and mid 1980s.

However, in both cases the overall pattern shows Canada's forest sector moved towards being more unsustainable over the period. On the balance, the evidence derived from net investment measures indicates unsustainability of Canada's forest sector for 1970-91. This implies that Canada's forest sector followed an unsustainable path over the period and the overall capital stock declined due to insufficient funds to reinvest in the sector to offset depreciation of man-made capital and timber resources.

In spite of these results, it is very difficult to conclude whether or not Canada's forest sector was sustainable for 1970-91. Two weak sustainability indicators presented the opposite conclusions from those derived from NP(2) and the V-H approach. As seen in adjusted forest sector NDP measure, Canada's forest sector was narrowly sustainable in spite of methodological differences of the economic depreciation estimation. On the other hand, the net investment measure suggested that Canada's forest sector was generally unsustainable. As stated by Hanley et al. (1999), however, these contrasting results are not so surprising, given different indicators have different messages about sustainability. This is because each measure adopts a unique definition of what sustainability actually means. Adjusted forest sector NDP considers sustainability as increasing level of the Hicksian notion of sustainable income, while net investment defines sustainability as a non-declining level of overall capital stocks.

The weak sustainability measures will offer a common implication for achieving weak sustainability for decision-makers and, to some extent, the general public. It requires adequate levels of re-investment in man-made capital. If investment in man-made capital is adequate to cancel out the effects of natural resource depletion and environmental degradation over time, then Canada's forest sector could be on a sustainable path over time. In Hartwick's framework, this would ensure that the wealth of Canada's forest sector remains constant because the maximum level of timber production is determined to be less than or equal to non-declining wealth of the forest sector.

The overall investment level in Canada's forest sector was falling relative to economic depreciation of timber resources over the period 1970-91. Hence, Canada's forest sector should raise the investment level to maintain the sustainable use of timber resources. It is, however, important to note that weak sustainability indicators might not intended as accurate measures of sustainability, since they do not account for important components to be considered, such as technological change and human capital accumulation. For example, the net investment measure only concerns the quantity of investment, it must equally focus on the quality of investment. In practice, as stated by Natural Resources Canada (1999), investment in human capital and research and development (R&D) of the forest sector must be one of the significant ways to achieve sustainable development of timber resources.

4.2 Future Research

This analysis has been a useful exercise to demonstrate that there are several ways to calculate economic depreciation of timber resources and measure sustainability. The estimated results lead us to useful, but different, conclusions about weak sustainability. There are many challenges for future research to obtain more accurate economic valuations of natural resources and measures of sustainability.

The first challenge is to standardize a valuation methodology for renewable natural resources. In this analysis, two methodologies: the net price approach and the Vincent-Hartwick approach were mainly discussed. While the net price approach (the NP(1) in this study) are most commonly discussed in the literatures on the economic rent calculation of renewable natural resources, there is no consensus that these are standardized valuation methodologies.

The net price approach can be conceptually improved by taking into account the growth stock effect, from the simple product of timber rent times the change of timber stocks in a given year. The methodological adjustment of the net price approach (the NP(2)) is generally expected to provide smaller economic depreciation values because of the stock effect, although it was not clearly observed in this analysis due to a relatively small impact of the marginal growth stock effect on the NP(2) calculation.

The Vincent-Hartwick approach is a considerably more complex methodology than the net price approach. It accounts for the age effect (remaining time in years to maturity), the net price approach implicitly assume that newly regenerated timber can be harvested immediately. This analysis clearly showed that the V-H approach provided lower estimates of economic depreciation of Canada's timber resources during the period 1970-91, compared with other methods, such as the total timber rents using value-added and the net price approach. This is because the net price approach overstates results by omitting the increasing capitalized value of immature forests.

It is difficult to conclude which methodology is the best for estimating the economic depreciation of Canada's timber resources from this study. Research is limited by the quality and quantity of data. However, the clearest lesson from this case study is the importance of standardizing valuation methodology for renewable natural resources. The difference of methodologies and assumptions bring different estimation results. As mentioned by Sedoff (1995), "natural resource accounts without a standardized valuation methodology cannot provide a consistent analytical framework for natural resources and environmental management" (p.53).

The second research challenge is associated with improving the accuracy of data. This study used mainly secondary time series data, such as Econnections and Canadian Forestry Statistics from Statistics Canada, Selected Forestry Statistics Canada from the Canadian Forest Service of Natural Resources Canada, and Canada's Forest Inventory 1991 (CanFI91) from Lowe, Power, and Gray (1994). Statistics Canada's Canadian Forestry Statistics and CANSIM Series provide robust secondary industrial data regarding Canada's forest sector based on a national census of manufacturing industry activities (Anielski 1991). They help to obtain accurate estimated results of economic depreciation of Canada's timber stock, since there are difficulties in aggregating data of stumpage fees across provinces and in knowing how stumpage reflects the market value of timber under varying forest tenure policy frameworks.

As discussed in Chapter 3, there is an accuracy problem with Canada's forest inventory data (both volume and area). According to Statistics Canada (1997), detailed and consistent stock data for Canada's forest are not currently available as a time series. Age-class distributions are necessary for distinguishing mature and immature forest areas in the Vincent and Hartwick approach. Forest inventories are conducted by the provincial and territorial forest inventory agencies every five years, which lead to provincial inventory standards and therefore inconsistent national inventory. For example, the numerical difference between the 1986 and 1991 inventories are not necessarily due to the real changes during the five-year period. The timing of the source inventories (i.e. provincial inventories) and when they are included in the national inventory are influenced the aggregate inventory and lead to apparent changes that are not necessarily real.

To overcome the lack of consistent stock data, Statistics Canada (1997) attempted to estimate the stock/flow time series data of timber resources for 1961-90 using a simulation model. In this study, the simulated results were used as physical timber accounts of Canada and the information to adjust the age-class distribution for 1970-91. However, the simulated age-class distribution by Statistics Canada was different from the 1991 age-class distribution from Canada's Forest Inventory 1991 (Statistics Canada 1997).[67] The problems associated with forest inventory data, in particular the age-class distribution, emphasizes the need for a more consistent way of aggregating provincial inventories.

The third challenge is related to the variety of assumptions that are considered throughout this study. For example, the net price approach and the Vincent-Hartwick approach depend on numerous assumptions including perfect competition, no uncertainty, constant output price and

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[67] The simulated age-class distribution by Statistics Canada is not available in the form of time series. Statistics Canada (1997) shows the discrepancy between their simulated age-class distribution of the stocked forestland in 1991 and the age-class distribution given by Canada's Forest Inventory (CanFI91) by using only figures.

harvesting costs, linear cost function and so forth. As well, it was assumed that the economy was closed and that there was an absence of technological change.

Indeed, these assumptions show the limitations of economic analysis in estimating natural resource values. As stated by Haener (1998), economic valuation methodologies for forest resource accounts rely on assumptions that are not necessarily considered realistic. In reality, output prices and harvesting costs are likely to change with uncertainty. When the economic valuation of natural resources is extended to the future, it is difficult to predict the direction and magnitudes of changes in prices and costs, as well as harvesting levels. We have to incorporate our expectations, or at least our best guesses, into the calculation. While these assumptions might be justified for simplifying the presentation of the methodologies, relaxing these assumptions may be necessary interesting, but very complicated, avenues for future research.

Fourth, the most challenging but interesting avenue for future research relates to the values of non-timber goods and services, such as recreational use, wildlife species of animals and plants, biodiversity, environmental control functions (e.g. air purification and carbon sequestration), and so on. While there is a certain consensus that these values should be fully reflected in forest resource accounts, this study does not include any non-timber goods and services for the accounting system. In this analysis, the value is assigned to timber removed from Canada's timber productive forestlands. Needless to say, a significant portion of Canada's forest resource accounts would be represented by non-timber goods and services. Therefore, the economic valuation excluding non-timber values does not give us the right picture of the total economic value of forest resources, and the true gains and losses in social values associated with forest resources are clearly understated.

Indeed, there has not been an estimation of non-timber asset values at the national level. This is because there are methodological difficulties for estimating them and cost constraints to collecting the necessary primary data. However, continuous effort to improve estimates of the shadow prices for non-timber goods and services should not be abandoned. Rigorous and objective scientific monitoring of not only ecological components but also public perceptions and preferences regarding a variety of goods and services of Canada's forests at the larger scale significantly reduces the lack of scientific and social consensus of ecological criticality. As well, it helps to create a linkage to natural resource accounts. The relationship between environmental quality and non-timber values determined by monitoring would provide useful information toward forming accurate pictures of forest resources and early warning signs as if when forest resources are depreciating (Adamowicz and Veeman 1998).

Finally, this analysis did not use strong sustainability indicators to measure sustainability of Canada's timber resources. As noted earlier, this is because strong sustainability indicators do not provide the explicit specification of baselines and norms of ecological criticality and the spatial and temporal scale levels. Without a rigorous framework and scientific consensus on how to establish baselines, strong sustainability indicators would be extremely arbitrary. Weak sustainability and strong sustainability are essentially different frameworks and cannot be assessed by the same criteria. Indeed, as stated by Rennings and Wiggering (1997), "up to now there has been only very little success to link both concepts or draw their boundaries" (p.26).

Weak sustainability indicators are not only criteria to measure sustainability. Various alternative measures should be discussed. Different indicators may provide different insights. Hanley et al. (1999) state that: "The general understanding of what we mean by 'sustainable development' suggests that it is too important to ignore in this way" (p.69). The further development of strong sustainability must bring one of those alternatives. In addition, a linkage between weak sustainability and strong sustainability will lead to a more balanced definition of sustainable development.

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Appendix I Calculation of the Optimal Rotation Age

The optimal rotation age (t^*) can be determined as a maximization problem of the forestland value (LV_t)[1], the present value of the stream of receipts minus expenditures forthcoming from the continued use of the land in timber growing (Howe 1979). In the calculation of the optimal rotation age (t^*), the role of the land value (LV_t) was correctly incorporated by the German forester Martin Faustmann in 1849. The costs and benefits associated with postponing the harvest another year suggests that trees must be allowed to continue growing as long as the incremental gain in the timber rent value exceeds the annual opportunity costs from not harvesting, which are including forgone annual interest on the timber rents plus the rental value of newly planted land (Howe 1979).[2]

The formula of the land value (LV_t) accounting for regeneration costs is given as:

$$LV_t = [p^*Y_t - c - sc(1 + r)^t]/[(1 + r)^t - 1] \qquad (1)$$

where $p^*Y_t - c$ = timber rents of cutting timber per hectare; sc = costs of planting per hectare; r = social discount rate; and Y_t = yield curve, which expresses the pattern of growth of timber with the age of tree.

The optimal rotation ages in British Columbia (BC) and the rest of Canada (RC) are separately calculated. This is because BC's harvest volumes, timber rents, pattern of growth are significantly different from RC's. From equation *(1)*, these factors lead to different optimal rotation ages between BC and RC.

To simplify the problem, it is assumed that: 1) the only benefits from commercial timber are focused; 2) the land remains permanently in timber growing; 3) all standing trees are clear-cut when they reach harvesting age (even-aged forests); and 4) no taxes or management costs will be incurred as trees grow.

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[1] This is also called the site expectation value, site value, soil rent, or bare land value in the forestry literature.

[2] This relationship is expressed as:

$\Delta TR = rTR_t + rLV_t \qquad (2)$

The term on the left-hand side of equation *(2)* implies the incremental gain in the timber rent value and the term on the right-hand side implies the annual opportunity costs of holding the land, including forgone annual interest on the timber rents plus the rental value of newly planted land. At the optimal rotation age (t^*), this equality will be satisfied. In other words, the optimal rotation age is the age at which the present value cannot be increased by letting trees grow by another year, that is $\Delta LV_t = 0$. However, if any rotation age is less than t^*, then trees must be allowed to continue growing because $\Delta TR > rTR_t + rLV_t$, and if any rotation age is greater than t^*, then they are harvested immediately because $\Delta TR < rTR_t + rLV_t$.

In the determination of the optimal rotation age (t^*), it is also assumed that the unit output prices (p) and the unit average harvesting costs (c) and planting costs (sc) are constant over time. The roundwood products price per cubic meters and the harvesting costs per hectare in the logging industry during the period 1970-93 are calculated from Statistics Canada, Catalogue. No.25-101 and 25-202 (Table 3.13 and 3.15 for BC and Table 3.14 and 3.16 for RC).

The unit price of timber (p) is represented by the average of roundwood products price (per cubic meters) during the period 1970-93: $46.7 per cubic meters in BC and $32.2 per cubic meters in RC (Table 3.13 and 3.14). The unit harvesting costs (c) are estimated by taking the average of harvesting cost (per hectare) in the logging industry for 1970-93: $7,917.2 per hectare in BC and $2,701.1 per hectare in RC (Table 3.15 and 3.16).

The costs of planting (sc) per hectare were represented by silviculture expenditures. This data is available from Canadian Council of Forest Ministers, National Forestry Database. BC's average silviculture costs for 1970-93 were $536.6 per hectare, and RC' were $721.1 per hectare (Table A.I-1).

The determination of the social discount rate is always controversial.[3] However, in this analysis, a social discount rate (r) is assumed 4 per cent, reflecting the average provincial government real borrowing rate over the period since 1961, that Statistics Canada (1997) suggests in their calculation of timber asset stock value. The social discount rate is in the line with the discount rate range, 2-4 per cent, for developed countries that Dixon, Hamilton, and Kunte (1997) suggested.

Based on the 1991 age-class distribution (timber volume in qubic meters per hectare) in Table 3.12, the following timber volume growth functions (Y_t) in BC and RC are estimated using least squares:

$$Y(t) = 3696.1 * (1 - \exp(-0.001t)^{1.33} \qquad \text{(BC)}$$

$$Y(t) = 172.4 * (1 - \exp(-0.02t)^{1.39} \qquad \text{(RC)}$$

---

[3] The social discount rate will be interesting subject of sensitivity analysis. It is expected that a higher/lower discount rate will increase/decrease the incremental costs of timber harvesting and thereby shorten/lengthen the optimal rotation age. This relationship is obvious from equation *(2)*. A higher/lower rate of discount will increase/decrease the annual opportunity costs of postponing harvest (the term on the right-hand side of equation *(2)*) and shorten/lengthen the optimal rotation age.

Table A.I-1 Silviculture Expenditures (British Columbia and the rest of Canada)

Britich Columbia

	(Millions of current $)		(Constant 1986 $)	(Hectares)	
Year	Silviculture Cost	Implicit PPI		Harvest (area)	SC per hectare
	1)	2)	3)	4)	5)=3)/4)
1977	38.3	56.6	67,700,000	327,300	206.8
1979	60.9	66.0	92,300,000	353,700	261.0
1981	98.4	80.9	121,600,000	280,000	434.3
1983	109.8	92.3	119,000,000	326,400	364.6
1985	167.8	97.7	171,800,000	348,000	493.7
1988	256.4	109.6	233,900,000	388,000	602.8
1989	267.1	114.9	232,500,000	389,100	597.5
1990	298.4	118.6	251,600,000	328,200	766.6
1991	395.9	121.9	324,800,000	381,900	850.5
1992	323.6	123.4	262,200,000	387,200	677.2
1993	317.1	124.7	254,300,000	392,500	647.9
Average					536.6

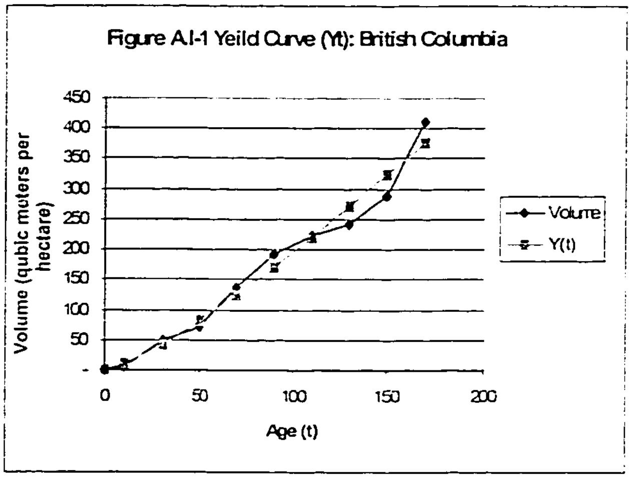
Source: Canadian Council of Forest Ministers, National Forestry Database.

the Rest of Canada

	(Millions of current $)		(Constant 1986 $)	(Hectares)	
Year	Silviculture Cost	Implicit PPI		Harvest (area)	SC per hectare
	6)	7)	8)	9)	10)=8)/9)
1977	80	56.6	141,300,000	327,300	431.7
1979	105	66.0	159,100,000	353,700	449.8
1981	174.5	80.9	215,700,000	280,000	770.4
1983	226.1	92.3	245,000,000	326,400	750.6
1985	312.8	97.7	320,200,000	348,000	920.1
1988	413.9	109.6	377,600,000	388,000	973.2
1989	416.9	114.9	362,800,000	389,100	932.4
1990	426.1	118.6	359,300,000	328,200	1,094.8
1991	407	121.9	333,900,000	381,900	874.3
1992	382.5	123.4	310,000,000	387,200	800.6
1993	349.3	124.7	280,100,000	392,500	713.6
Average					727.1

Source: Canadian Council of Forest Ministers, National Forestry Database.

It is assumed that the functions have logistic shapes. In the case of logistic functions, the timber growth rate (the current annual increment) declines as the forest grows to maturity (Figure A.I-1 and Figure A.I-2).[4] The rest of Canada's yield curve (Y_t) is estimated as aggregation of timber volume growth functions of 7 provinces (Newfoundland, Nova Scotia, New Branswick, Quebec, Ontario, Saskatchewan, and Alberta) and Yukon Territory.



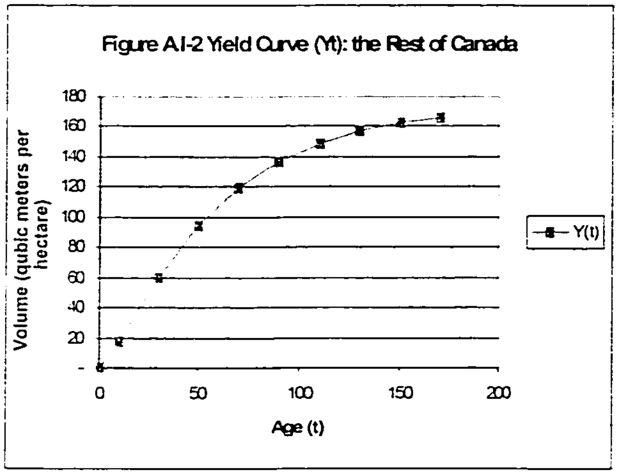


Table A.I-2 shows the determination of the optimal rotation ages of BC and RC in both cases of the land value (LV_t) with and without regeneration costs. As noted earlier, the optimal rotation age (t^*) is defined when LV_t will generate the highest value. The maximum values of LV_t are occurred when the rotation age (t) is 115 years in BC and 63 years in RC without regeneration costs and 120 years in BC and 79 years in RC with regeneration costs. Thus, the optimal rotation age (t^*) are determined as 115 years in BC and 63 years in RC and 120 years in BC and 79 years in RC, respectively.[5] The optimal rotation age becomes longer when regeneration costs are incorporated into the land value calculation.

[4] However, the estimated BC's yield curve (Y_t) would not support this assumption clearly, while the estimated RC's yield curve (Y_t) does. Even after the age of 161 years, the current annual increment is growing.

[5] In the case of BC, the estimate results (t^* = 115 and 120) might be supported by the case study to calculate the optimal rotation age for Douglas fir in British Columbia shown in Howe (1979). The calculated optimal rotation age was 122 years and 104 years with the discount rates of 6 per cent and 10 per cent, respectively.

Table A.I-2 Determination of the Optimal Rotation (British Columbia and the Rest of Canada)

Without regeneration costs

British Columbia
r = 0.04

t	p(t) ($ (1986=100))	c(t)	Y(t)	Land Value(t)
	1)	2)	3)	4)=[1)*3)-2)]/[(1+r)^t-1]
50	46.7	7,917.2	81.0	(677.14)
60	46.7	7,917.2	102.4	(329.51)
70	46.7	7,917.2	124.6	(143.88)
80	46.7	7,917.2	47.7	(46.30)
90	46.7	7,917.2	171.3	2.55
100	46.7	7,917.2	195.6	24.56
105	46.7	7,917.2	207.9	29.61
110	46.7	7,917.2	220.3	32.12
111	46.7	7,917.2	222.8	32.38
112	46.7	7,917.2	225.2	32.58
113	46.7	7,917.2	227.8	32.72
114	46.7	7,917.2	230.3	32.80
115	46.7	7,917.2	232.8	32.83
116	46.7	7,917.2	235.3	32.80
117	46.7	7,917.2	237.8	32.73
118	46.7	7,917.2	240.3	32.62
119	46.7	7,917.2	242.8	32.48
120	46.7	7,917.2	245.4	32.29
121	46.7	7,917.2	247.9	32.07

Rest of Canada
r = 0.04

t	p(t) ($ (1986=100))	c(t)	Y(t)	Land Value(t)
	5)	6)	7)	8)=[5)*7)-6)]/[(1+r)^t-1]
50	32.2	2,701.1	94.6	56.34
55	32.2	2,701.1	101.7	75.05
56	32.2	2,701.1	103.1	77.26
57	32.2	2,701.1	104.4	79.07
58	32.2	2,701.1	105.7	80.51
59	32.2	2,701.1	107.0	81.62
60	32.2	2,701.1	108.3	82.43
61	32.2	2,701.1	109.5	82.97
62	32.2	2,701.1	110.7	83.25
63	32.2	2,701.1	111.9	83.32
64	32.2	2,701.1	113.1	83.18
65	32.2	2,701.1	114.3	82.87
66	32.2	2,701.1	115.4	82.39
67	32.2	2,701.1	116.5	81.77
68	32.2	2,701.1	117.6	81.03
69	32.2	2,701.1	118.7	80.16

With regeneration costs

British Columbia
(r = 0.04)
($ (1986=100))

t	p(t)	c(t)	Y(t)	sc (t)	Land Value(t)
	1)	2)	3)	4)	5)=[1)*3)-2)-4)*(1+r)^t]/[(1+r)^t-1]
50	46.7	7,917.2	81.0	536.6	(1,301.61)
60	46.7	7,917.2	102.4	536.6	(922.47)
70	46.7	7,917.2	124.6	536.6	(717.30)
80	46.7	7,917.2	147.7	536.6	(607.24)
90	46.7	7,917.2	171.3	536.6	(550.25)
100	46.7	7,917.2	195.6	536.6	(522.88)
105	46.7	7,917.2	207.9	536.6	(515.87)
110	46.7	7,917.2	220.3	536.6	(511.76)
115	46.7	7,917.2	232.8	536.6	(509.74)
116	46.7	7,917.2	235.3	536.6	(509.53)
117	46.7	7,917.2	237.8	536.6	(509.38)
118	46.7	7,917.2	240.3	536.6	(509.27)
119	46.7	7,917.2	242.8	536.6	(509.22)
120	46.7	7,917.2	245.4	536.6	(509.20)
121	46.7	7,917.2	247.9	536.6	(509.23)
122	46.7	7,917.2	250.4	536.6	(509.29)
123	46.7	7,917.2	253.0	536.6	(509.39)
124	46.7	7,917.2	255.5	536.6	(509.52)
125	46.7	7,917.2	258.0	536.6	(509.68)

the Rest of Canada
(r = 0.04)
($ (1986=100))

t	p(t)	c(t)	Y(t)	sc(t)	Land Value(t)
	6)	7)	8)	9)	10)=[6)*8)-7)-9)*(1+r)^t]/[(1+r)^t-1]
50	32.2	2,701.1	94.6	727.1	(789.83)
55	32.2	2,701.1	101.7	727.1	(747.15)
60	32.2	2,701.1	108.3	727.1	(721.05)
65	32.2	2,701.1	114.3	727.1	(705.86)
70	32.2	2,701.1	119.7	727.1	(697.80)
75	32.2	2,701.1	124.7	727.1	(694.35)
76	32.2	2,701.1	125.7	727.1	(694.05)
77	32.2	2,701.1	126.6	727.1	(693.86)
78	32.2	2,701.1	127.5	727.1	(693.76)
79	32.2	2,701.1	128.4	727.1	(693.74)
80	32.2	2,701.1	129.3	727.1	(693.81)
81	32.2	2,701.1	130.1	727.1	(693.94)
82	32.2	2,701.1	131.0	727.1	(694.14)
83	32.2	2,701.1	131.8	727.1	(694.39)
84	32.2	2,701.1	132.6	727.1	(694.69)
85	32.2	2,701.1	133.4	727.1	(695.03)

Appendix II Adjustments of the Age-Class Distribution

Adjustments are made to obtain the 1970-91 age-class distributions in British Columbia and the rest of Canada. The age-class distribution in the rest of Canada is estimated as the difference between the age-class distributions in Canada and British Columbia.

Adjustments are made in the following order:

1) The changes of total timber productive areas are estimated for 1970-1991. Statistics Canada (1997) provides this information for 1961-90. However, Statistics Canada (1997) does not show the simulation results of the age-class distribution during the period. Beginning with 1991 inventory data from Canada's Forestry Inventory 1991 (CanFI91) (Table A.II-2 and A.II-5), the total areas (excluding unclassified areas) is estimated backwards to 1970 from 1991 with the annual percentage change of total timber stock areas from Statistics Canada (1997) (Table A.II-1 and A.II-3). The estimated total area becomes bigger than the simulated total area by Statistics Canada throughout the period.

2) In order to eliminate nonstocked and stocking unproven categories from the age-class distribution, nonstocked (including 60 per cent of unproven stocking) is allocated to age-class 0, and the 40 per cent of unproven stocking is allocated to the youngest age-class 1-20 (Table A.II-2 and A.II-5) (Lowe, Power, and Gray 1994).

3) In CanFI91, the age-classes are given of equal intervals by 20 years (Table A.II-2 and A.II-5). The 1991 distributions of area by each 20-year interval age-class are divided by 20 and allocated to one-year interval age-classes (1-161) evenly.

4) The timber productive area of the 0 age-class in year t ($A_{0,t}$) is given as:

$$A_{0,t} = [A_{0,t+1} - A_{H,t} + A_{1,t+1} - A_{NH,t} - A_{L,t}]/[1 - i_t]$$

where $A_{H,t}$ = harvested area in year t (Statistics Canada 1997); $A_{NH,t}$ = lost area by non-harvest disturbance factors (i.e. the sum of fire, mortality, and roads) (Statistics Canada 1997); $A_{L,t}$ = annual change of the estimated total timber productive area from year t+1 to year t; and i_t = percentage of lost area by non-harvest disturbance factors ($A_{L,t}$) to the estimated total timber productive area.

5) The timber productive areas of the 1-161 age-classes in year t ($A_{1,t}$.....$A_{161,t}$) are derived as:

For $A_{1,t}$, $IF(A_{2,t+1} > 0, A_{2,t+1}/(1 - I_t), IF(A_{1,t+1} > 0, A_{H,t}/(1 - I_t), 0))$

The sum of the 0-161 age-classes in year t will be equal to the estimated total timber productive area in the same year.

6) As a result of these adjustments, British Columbia has negative timber productive areas of the 0 age-class from 1970 to 1977. This is because CanFI91 does not account for regeneration in the first 30 age-classes (Statistics Canada 1997). To adjust negative values, negative value in 1970 (−1957 thousands of hectares) is added to the youngest age-classes (1-20) evenly and subtracted from the older age-classes (21-161) evenly. Table A.II-3 shows the estimated result after adjustment of negative numbers.

Consequently, the adjusted age-class distributions of area by 20-year intervals are summarized for 1970-1991 in Table A.II-3 and Figure A.II-1 for British Columbia and Table A.II-6 and Figure A.II-2 for Canada. In Table A.II-7 and Figure A.II-3, the adjusted age-class distribution in the rest of Canada is derived from the difference between Canada and British Columbia.

Table A.II-1 Variations of Timber Stocks (Area) (British Columbia)

Year	Nonreserved accessible opening stock	Harvest	Fire	Mortality	Roads	Regeneration	Nonreserved accessible closing stock	Nonreserved nonstocked accessible closing stock	Total area
1990	32,759.9	328.2	26.1	66.7	9.9	431.1	32,760.1	2,662.8	35,422.9
1989	32,762.0	389.1	5.5	65.4	11.7	469.5	32,759.9	2,672.8	35,432.7
1988	32,764.1	388.0	1.6	63.7	11.6	463.0	32,762.0	2,682.4	35,444.4
1987	32,766.9	406.7	11.1	61.9	12.2	489.1	32,764.1	2,691.9	35,456.0
1986	32,767.3	349.4	4.7	59.7	10.5	423.9	32,766.9	2,701.4	35,468.3
1985	32,767.6	348.0	26.9	57.3	10.4	442.3	32,767.3	2,711.4	35,478.7
1984	32,767.5	338.9	6.1	54.6	10.2	409.8	32,767.6	2,721.6	35,489.2
1983	32,766.8	326.4	16.3	51.6	9.8	404.7	32,767.5	2,731.8	35,499.3
1982	32,763.4	258.0	139.1	48.1	7.7	456.3	32,766.8	2,742.3	35,509.1
1981	32,760.8	280.0	28.4	44.6	8.4	364.0	32,763.4	2,753.5	35,516.9
1980	32,760.7	345.2	16.2	44.5	10.4	416.4	32,760.8	2,764.5	35,525.3
1979	32,760.9	353.7	9.2	44.5	10.6	417.8	32,760.7	2,774.9	35,535.6
1978	32,760.9	350.2	17.7	44.4	10.5	422.8	32,760.9	2,785.3	35,546.2
1977	32,760.0	327.3	0.8	44.2	9.8	383.1	32,760.9	2,795.8	35,556.7
1976	32,759.0	326.5	8.8	44.0	9.8	390.1	32,760.0	2,806.6	35,566.6
1975	32,754.3	236.4	4.2	43.7	7.1	296.1	32,759.0	2,817.4	35,576.4
1974	32,751.5	284.6	5.0	43.4	8.5	344.3	32,754.3	2,829.2	35,583.5
1973	32,750.5	333.3	10.2	43.1	10.0	397.5	32,751.5	2,840.5	35,592.0
1972	32,747.0	269.0	3.0	42.8	8.1	326.3	32,750.5	2,851.4	35,601.9
1971	32,743.4	270.3	63.6	42.3	8.1	387.9	32,747.0	2,863.1	35,610.1
1970	32,739.5	262.5	24.6	42.0	7.9	340.9	32,743.4	2,874.7	35,618.1
1969	32,735.3	257.6	35.6	41.6	7.7	346.7	32,739.5	2,886.5	35,626.0

Source: Statistics Canada, Econnections, 1997.

Table A.II-2 Canada's Forest Inventory 1991 (CanFI91) (British Columbia)

(Thousands of hectares)

Year		Nonstocked	Stocking unproven	Stocked by age-class									
				0	1-20	21-40	41-60	61-80	81-100	101-120	121-140	141-160	161+
1991	Before adjustment	4,351.0	8.0	-	1,684.0	2,567.0	3,886.0	4,735.0	4,890.0	5,589.0	3,887.0	15,013.0	4,933.0
	Adjustment - a			4,351.0									
	Adjustment - b			4.8	3.2								
	After adjustement			4,355.8	1,687.2	2,567.0	3,886.0	4,735.0	4,890.0	5,589.0	3,887.0	15,013.0	4,933.0

Uneven	Unclass	Total area
-	196.0	51,739.0
-	196.0	51,739.0

Notes: For adjustemnt - a, nonstocked (including 'unproven' stocking) is allocated to age-class 0.
For adjustment - b, the stocked portion of 'unproven' and 'unspecified' stocking is allocated to the youngest age-class (1-20).
Source: Appendix1, Table 16.5 from Canada's Forest Inventory 1991 (Lowe, Power, and Gray 1994).

Table A.II-3 Adjusted Age-Class Distribution (British Columbia)

(Thousands of hectares)

Year	Stocked by age class										Total area
	0	1-20	21-40	41-60	61-80	81-100	101-120	121-140	141-160	161+	
1970	100.9	2,435.1	3,778.0	4,622.0	4,810.9	5,411.0	4,311.6	14,745.2	6,637.2	5,258.3	52,110.3
1971	309.0	2,363.0	3,728.1	4,606.7	4,767.1	5,490.5	3,729.1	15,243.5	6,596.4	5,419.1	52,252.4
1972	491.4	2,429.8	3,650.9	4,551.7	4,747.6	5,441.1	3,807.9	14,632.2	7,071.4	5,386.2	52,210.3
1973	610.5	2,499.4	3,578.8	4,502.7	4,734.1	5,398.9	3,891.3	14,041.8	7,489.0	6,675.0	53,421.6
1974	805.2	2,568.3	3,506.0	4,453.0	4,719.8	5,355.6	3,973.7	13,450.1	7,952.5	5,698.9	52,483.0
1975	946.7	2,637.4	3,434.0	4,403.9	4,706.1	5,313.2	4,056.5	12,861.6	8,463.7	4,733.5	51,556.6
1976	1,034.6	2,706.4	3,362.2	4,355.2	4,692.7	5,271.1	4,139.1	12,275.0	8,883.5	6,538.7	53,258.5
1977	1,220.1	2,774.8	3,290.0	4,305.8	4,678.5	5,228.2	4,221.0	11,687.9	9,299.6	6,553.6	53,259.6
1978	1,397.9	2,843.6	3,218.6	4,257.3	4,665.1	5,186.3	4,303.2	11,104.2	9,692.8	7,014.8	53,683.8
1979	1,615.9	2,911.0	3,146.2	4,207.3	4,649.9	5,142.5	4,383.7	10,517.8	10,077.2	7,083.7	53,735.2
1980	1,829.7	2,978.7	3,074.5	4,158.1	4,635.7	5,099.8	4,464.6	9,935.0	10,470.3	6,914.5	53,560.8
1981	2,044.0	3,045.8	3,002.5	4,108.5	4,620.7	5,056.4	4,544.7	9,352.4	10,925.4	5,609.7	52,310.2
1982	2,203.8	3,112.1	2,930.2	4,058.2	4,604.8	5,012.0	4,623.5	8,769.5	11,397.5	5,181.5	51,893.1
1983	2,447.6	3,170.3	2,851.1	3,998.3	4,577.9	4,955.8	4,690.7	8,168.9	11,770.2	6,538.8	53,169.6
1984	2,647.6	3,236.2	2,779.6	3,948.7	4,562.4	4,912.2	4,769.1	7,592.1	12,157.1	6,788.3	53,393.2
1985	2,853.1	3,302.3	2,708.7	3,899.8	4,547.7	4,869.4	4,847.9	7,018.1	12,534.7	6,974.1	53,555.8
1986	3,090.1	3,366.4	2,636.7	3,849.1	4,530.7	4,824.4	4,924.0	6,442.6	12,902.6	6,999.2	53,565.9
1987	3,307.5	3,431.8	2,566.1	3,800.2	4,515.7	4,781.4	5,001.9	5,871.9	13,216.5	8,148.8	54,641.8
1988	3,592.7	3,496.1	2,495.1	3,750.6	4,499.7	4,737.6	5,078.4	5,301.8	13,544.5	7,772.7	54,269.2
1989	3,851.1	3,560.9	2,424.8	3,701.8	4,484.5	4,694.8	5,155.5	4,734.6	13,871.8	7,795.7	54,275.6
1990	4,118.3	3,625.0	2,354.4	3,652.8	4,468.9	4,651.5	5,231.7	4,168.7	14,256.6	6,578.4	53,106.1
1991	4,355.8	3,687.2	2,283.3	3,602.3	4,451.3	4,606.3	5,305.3	3,603.3	14,729.3	4,649.3	51,273.5

Figure A.II-1 Adjusted Age-Class Distribution (British Columbia): 1970-91

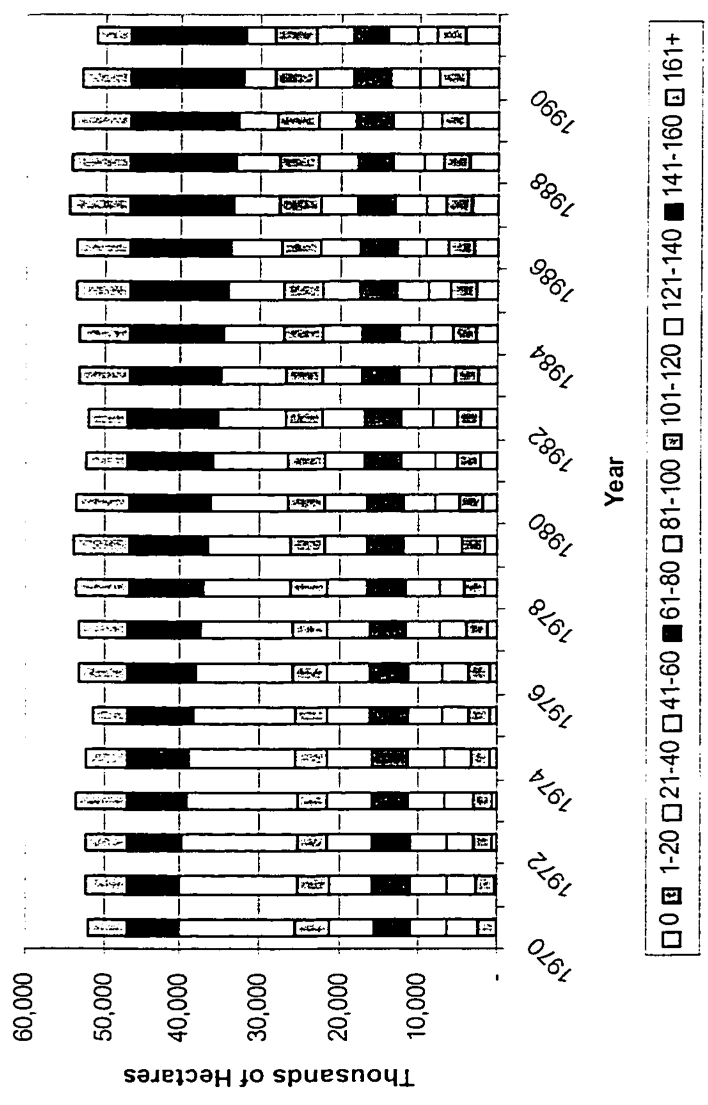


Table A.II-4 Variations of Timber Stocks (Area) (Canada)

(Thousands of hectares)

Year	Nonreserved Accessible Opening Stock	Harvest	Fire	Mortality	Roads	Regeneration	Nonreserved Accessible Closing Stock	Nonreserved Nonstocked Accessible Closing Stock	Total Area
1990	125,401.6	1,114.2	126.3	173.3	33.4	1,469.7	125,424.1	13,351.6	138,775.7
1989	125,387.1	1,318.9	1,229.5	181.4	39.6	2,783.9	125,401.6	13,407.5	138,809.1
1988	125,374.4	1,373.3	179.4	192.0	41.2	1,798.5	125,387.1	13,461.6	138,848.7
1987	125,361.6	1,374.6	111.3	201.7	41.2	1,741.7	125,374.4	13,515.4	138,889.8
1986	125,345.5	1,301.3	158.5	211.9	39.0	1,726.7	125,361.6	13,569.5	138,931.1
1985	125,326.1	1,225.1	62.8	222.4	36.8	1,566.5	125,345.5	13,624.6	138,970.1
1984	125,306.7	1,233.1	51.8	233.7	37.0	1,574.9	125,326.1	13,680.8	139,006.9
1983	125,283.2	1,136.7	176.5	245.2	34.1	1,616.0	125,306.7	13,737.1	139,043.8
1982	125,251.5	939.1	375.9	256.5	28.2	1,631.5	125,283.2	13,794.7	139,077.9
1981	125,225.5	1,089.0	451.4	269.3	32.7	1,868.4	125,251.5	13,854.6	139,106.1
1980	125,200.5	1,120.4	482.7	270.0	33.6	1,931.7	125,225.5	13,913.3	139,138.8
1979	125,177.5	1,178.8	81.1	271.4	35.4	1,589.6	125,200.5	13,972.0	139,172.5
1978	125,152.2	1,129.3	22.4	272.0	33.9	1,482.9	125,177.5	14,030.3	139,207.8
1977	125,123.5	1,050.4	158.1	272.2	31.5	1,540.8	125,152.2	14,089.5	139,241.7
1976	125,092.2	996.1	196.4	272.3	29.9	1,525.8	125,123.5	14,149.7	139,273.2
1975	125,055.4	863.1	34.5	272.1	25.9	1,232.4	125,092.2	14,210.8	139,303.0
1974	125,025.3	1,040.2	218.4	272.9	31.2	1,592.8	125,055.4	14,273.6	139,329.0
1973	124,995.3	1,049.3	19.6	273.9	31.5	1,404.3	125,025.3	14,334.8	139,360.1
1972	124,959.8	919.8	126.8	273.7	27.6	1,383.4	124,995.3	14,396.3	139,391.6
1971	124,922.6	885.2	236.3	273.5	26.6	1,458.8	124,959.8	14,459.4	139,419.2
1970	124,886.6	921.7	225.7	274.1	27.7	1,485.2	124,922.6	14,523.2	139,445.8
1969	124,850.6	932.7	181.0	274.9	28.0	1,452.5	124,886.6	14,586.9	139,473.5

Source: Statistics Canada, Econnections, 1997.

Table A.II-5 Canada's Forest Inventory 1991 (CanFI91) (Canada)

(Thousands of hectares)

Year		Nonstocked	Stocking unproven	Stocked by age-class									
				0	1-20	21-40	41-60	61-80	81-100	101-120	121-140	141-160	161+
1991	Before adjustment	5,458.0	18,662.0	1,518.0	6,062.0	11,939.0	25,440.0	23,426.0	19,838.0	14,617.0	9,217.0	16,615.0	5,736.0
	Adjustment - a			5,458.0									
	Adjustment - b			11,197.0	7,465.0								
	After adjustment			18,173.0	13,527.0	11,939.0	25,440.0	23,426.0	19,838.0	14,617.0	9,217.0	16,615.0	5,736.0

Uneven	Unclass	Total area
206.0	86,638.0	245,370.0
206.0	86,638.0	245,370.0

Notes: For adjustment - a, nonstocked (including 'unproven' stocking) is allocated to age-class 0.
For adjustment - b, the stocked portion of 'unproven' and 'unspecified' stocking is allocated to the youngest age-class (1-20).
Source: Appendix1, Table 16.5 from Canada's Forest Inventory 1991 (Lowe, Power, and Gray 1994).

Table A.II-6 Adjusted Age-Class Distribution (Canada)

(Thousands of hectares)

Year	Stocked by age class										Total area
	0	1-20	21-40	41-60	61-80	81-100	101-120	121-140	141-160	161+	
1970	242.3	13,518.9	27,157.0	24,914.2	20,981.3	15,376.2	10,274.6	17,223.9	23,204.6	18,497.4	171,390.5
1971	1,023.8	12,751.6	27,171.4	25,020.4	21,188.2	15,611.8	9,844.3	17,745.8	22,543.0	17,766.0	170,666.3
1972	1,691.5	12,791.6	26,358.2	25,040.3	21,305.2	15,835.2	10,097.3	17,290.2	22,426.2	18,447.4	171,283.2
1973	2,282.1	12,840.2	25,568.3	25,077.4	21,436.3	16,068.2	10,355.8	16,849.5	22,194.0	21,030.5	173,702.4
1974	2,900.9	12,897.2	24,799.3	25,131.1	21,581.0	16,310.7	10,619.9	16,422.1	21,983.2	20,875.0	173,520.3
1975	3,711.2	12,937.1	24,002.5	25,151.9	21,697.0	16,530.8	10,868.8	15,975.8	21,920.4	17,299.4	170,094.9
1976	4,153.5	12,992.7	23,239.5	25,203.6	21,839.0	16,770.0	11,129.6	15,551.7	21,748.6	19,986.9	172,615.1
1977	4,890.0	13,033.9	22,455.4	25,227.5	21,956.4	16,989.6	11,376.9	15,112.9	21,496.6	21,071.4	173,610.6
1978	5,642.2	13,077.8	21,681.4	25,257.0	22,078.2	17,211.8	11,625.3	14,680.3	21,169.7	22,634.4	175,058.1
1979	6,342.4	13,132.8	20,930.0	25,308.2	22,218.4	17,447.6	11,882.5	14,262.5	20,810.4	23,635.7	175,970.4
1980	7,151.3	13,182.3	20,173.8	25,349.2	22,349.1	17,675.5	12,133.7	13,841.1	20,497.1	22,523.4	174,876.5
1981	8,284.3	13,197.1	19,370.8	25,323.7	22,420.6	17,855.5	12,351.4	13,386.8	20,158.7	21,887.5	174,236.3
1982	9,357.3	13,214.1	18,579.5	25,303.2	22,495.5	18,037.1	12,569.2	12,939.6	19,973.4	18,863.2	171,332.2
1983	10,184.6	13,238.8	17,806.2	25,297.7	22,582.9	18,227.5	12,792.4	12,504.0	19,600.4	22,801.8	175,036.2
1984	11,013.6	13,280.7	17,062.2	25,325.6	22,699.4	18,440.6	13,030.8	12,088.1	19,157.0	24,714.0	176,812.1
1985	11,814.4	13,333.9	16,336.6	25,375.2	22,835.0	18,668.5	13,279.3	11,684.8	18,737.9	24,553.6	176,619.1
1986	12,604.1	13,386.8	15,614.0	25,424.6	22,969.9	18,895.5	13,526.7	11,283.1	18,240.7	26,095.7	178,041.1
1987	13,547.9	13,431.8	14,885.9	25,459.0	23,091.0	19,110.5	13,765.1	10,876.8	17,659.0	27,555.7	179,382.6
1988	14,513.9	13,481.3	14,166.6	25,502.3	23,219.6	19,331.1	14,007.2	10,476.4	17,083.9	27,540.2	179,322.5
1989	15,532.7	13,525.3	13,445.4	25,535.5	23,338.6	19,543.1	14,242.6	10,073.9	16,546.9	26,630.3	178,414.4
1990	17,440.3	13,476.7	12,641.5	25,394.5	23,297.3	19,619.6	14,378.3	9,607.8	16,106.1	22,332.6	174,294.8
1991	18,173.2	13,526.8	11,939.0	25,440.0	23,426.0	19,838.0	14,617.0	9,217.0	16,615.0	5,736.0	158,528.0

Figure AII-2 Adjusted Age-Class Distribution (Canada): 1970-91

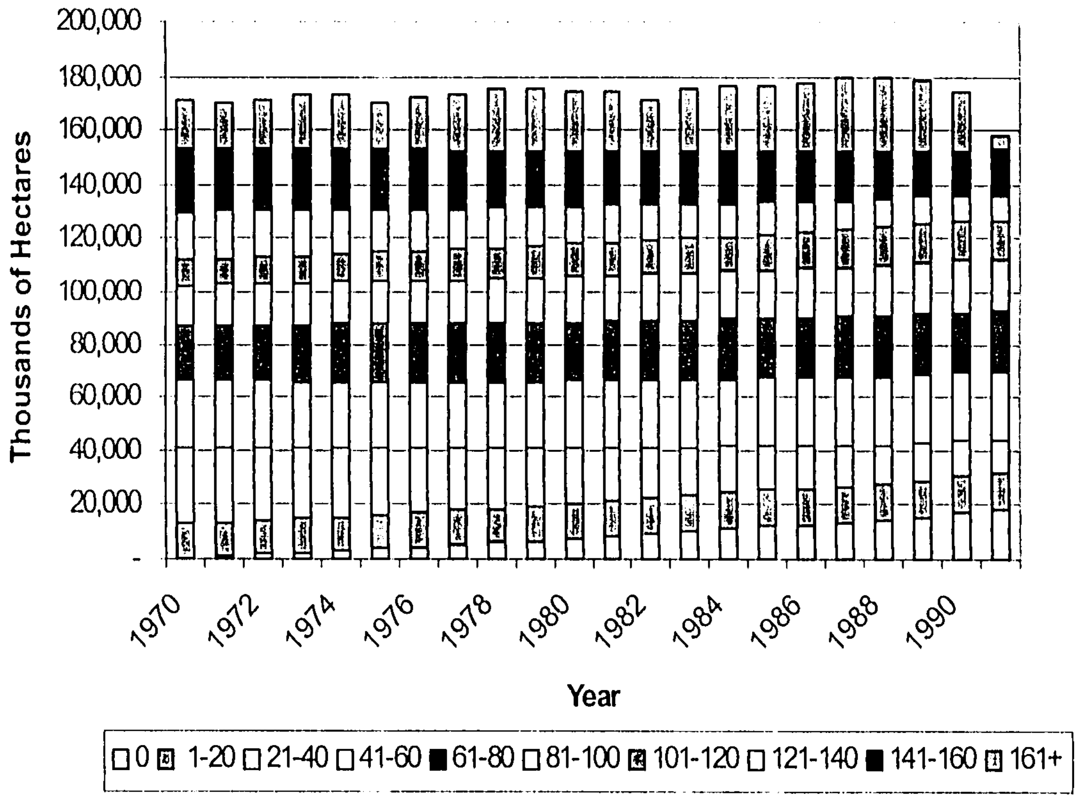
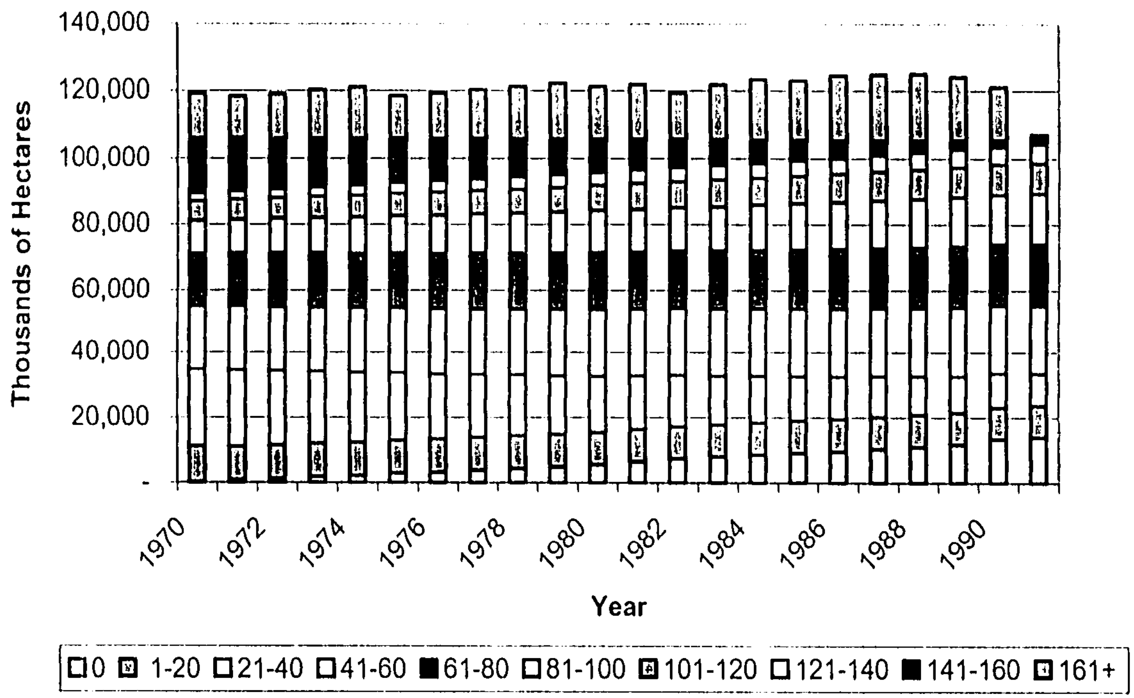


Table A.II-7 Adjusted Age-Class Distribution (the Rest of Canada = Canada - British Columbia)

(Thousands of hectares)

Year	Stocked by age class										Total area
	0	1-20	21-40	41-60	61-80	81-100	101-120	121-140	141-160	161+	
1970	141.4	11,083.8	23,379.1	20,292.2	16,170.4	9,965.2	5,963.0	2,478.7	16,567.3	13,239.1	119,280.3
1971	714.7	10,388.6	23,443.4	20,413.7	16,421.1	10,121.3	6,115.2	2,502.4	15,946.7	12,346.9	118,413.9
1972	1,200.1	10,361.8	22,707.3	20,488.6	16,557.7	10,394.1	6,289.4	2,658.0	15,354.8	13,061.2	119,072.9
1973	1,671.6	10,340.9	21,989.6	20,574.7	16,702.2	10,669.3	6,464.5	2,807.7	14,705.0	14,355.5	120,280.8
1974	2,095.7	10,328.9	21,293.3	20,678.1	16,861.2	10,955.1	6,646.1	2,972.0	14,030.7	15,176.1	121,037.3
1975	2,764.5	10,299.7	20,568.5	20,748.0	16,990.9	11,217.6	6,812.3	3,114.2	13,456.7	12,565.9	118,538.4
1976	3,118.9	10,286.3	19,877.4	20,848.4	17,146.3	11,498.9	6,990.5	3,276.6	12,865.1	13,448.2	119,356.6
1977	3,669.9	10,259.1	19,165.4	20,921.7	17,278.0	11,761.4	7,156.0	3,424.9	12,196.9	14,517.7	120,351.0
1978	4,244.2	10,234.3	18,462.7	20,999.8	17,413.1	12,025.5	7,322.1	3,576.1	11,476.9	15,619.6	121,374.3
1979	4,726.5	10,221.8	17,783.8	21,100.9	17,568.4	12,305.1	7,498.8	3,744.7	10,733.1	16,552.0	122,235.2
1980	5,321.6	10,203.6	17,099.3	21,191.0	17,713.5	12,575.7	7,669.1	3,906.2	10,026.8	15,608.9	121,315.7
1981	6,240.3	10,151.2	16,368.3	21,215.1	17,799.8	12,799.1	7,806.7	4,034.5	9,233.4	16,277.7	121,926.1
1982	7,153.6	10,102.1	15,649.3	21,245.0	17,890.7	13,025.0	7,945.7	4,170.1	8,575.9	13,681.7	119,439.1
1983	7,737.0	10,068.4	14,955.1	21,299.4	18,005.0	13,271.7	8,101.7	4,335.1	7,830.2	16,262.9	121,866.6
1984	8,366.0	10,044.5	14,282.5	21,376.9	18,137.0	13,528.4	8,261.8	4,496.1	6,999.9	17,925.7	123,418.9
1985	8,961.4	10,031.6	13,627.8	21,475.4	18,287.3	13,799.1	8,431.4	4,666.7	6,203.2	17,579.5	123,063.3
1986	9,514.0	10,020.4	12,977.3	21,575.5	18,439.2	14,071.1	8,602.7	4,840.5	5,338.1	19,096.5	124,475.2
1987	10,240.4	10,000.0	12,319.8	21,658.8	18,575.3	14,329.0	8,763.2	5,004.9	4,442.5	19,406.9	124,740.8
1988	10,921.2	9,985.1	11,671.5	21,751.7	18,719.9	14,593.5	8,928.8	5,174.6	3,539.5	19,767.4	125,053.3
1989	11,681.6	9,964.4	11,020.7	21,833.7	18,854.1	14,848.4	9,087.1	5,339.3	2,675.1	18,834.5	124,138.8
1990	13,322.0	9,851.8	10,287.1	21,741.8	18,828.4	14,968.2	9,146.6	5,439.1	1,849.5	15,754.2	121,188.6
1991	13,817.4	9,839.6	9,655.7	21,837.7	18,974.7	15,231.7	9,311.7	5,613.7	1,885.7	1,086.7	107,254.5

Figure A.II-3 Adjusted Age-Class Distribution (the Rest of Canada): 1970-91



Appendix III Tables

Table A.III-1 Industrial Bond Yield Average 10 Years (Canada)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual average
1970	9.32	9.28	9.24	9.21	9.28	9.24	9.11	9.19	9.19	9.22	9.02	8.83	9.18
1971	8.19	8.30	8.37	8.43	8.47	8.52	8.56	8.41	8.32	8.21	8.14	8.24	8.35
1972	8.24	8.21	8.24	8.28	8.30	8.34	8.34	8.39	8.46	8.41	8.25	8.15	8.30
1973	8.18	8.20	8.22	8.30	8.40	8.40	8.51	8.71	8.62	8.62	8.71	8.81	8.47
1974	8.98	8.98	9.26	9.91	10.12	10.45	10.81	11.02	10.99	10.40	10.34	10.72	10.17
1975	10.44	9.99	10.15	10.75	10.62	10.57	10.93	10.94	11.40	11.15	11.15	11.06	10.76
1976	10.75	10.69	10.82	10.64	10.57	10.74	10.68	10.42	10.33	10.25	10.04	9.83	10.48
1977	9.76	9.83	9.88	9.82	9.71	9.63	9.67	9.62	9.55	9.63	90.69	9.71	16.46
1978	9.92	9.94	9.95	9.96	9.95	9.95	9.87	9.89	9.93	10.26	10.25	10.34	10.02
1979	10.45	10.52	10.46	10.30	10.29	10.34	10.52	10.85	11.09	11.97	11.72	12.07	10.88
1980	12.08	13.35	13.89	12.84	12.29	12.15	13.19	13.35	13.74	13.95	13.72	13.62	13.18
1981	13.84	14.34	14.41	16.03	15.94	15.93	17.93	17.95	19.09	17.28	15.46	16.48	16.22
1982	16.87	17.12	16.85	16.65	16.82	17.80	17.27	15.99	14.78	13.61	13.58	13.05	15.87
1983	13.54	12.99	12.92	12.29	12.59	12.47	13.09	13.24	12.63	12.64	12.70	13.00	12.84
1984	12.91	13.35	13.98	14.28	14.66	14.77	14.02	13.43	13.40	12.94	12.63	12.41	13.57
1985	12.21	13.02	12.49	12.29	11.42	11.66	11.67	11.55	11.66	11.38	11.03	10.83	11.77
1986	11.34	10.87	10.57	10.67	10.80	10.70	10.76	10.69	10.93	10.95	10.83	10.79	10.83
1987	10.55	10.68	10.63	10.97	10.97	10.97	11.26	11.58	12.03	11.53	11.81	11.49	11.21
1988	11.02	11.04	11.22	11.42	11.32	11.21	11.44	11.62	11.45	11.23	11.47	11.54	11.33

Source: CANSIM Series B14016.

Table A.III-2 Annual Average Indices (Canada)

Year	Consumer price index (CP)		Implicit producer price index, GDP (a)		Exchange Rate ($CDN to $US)
	(1986=100)	Per cent change	(1986=100)	Per cent change	
1970	31.0	3.3	32.8	4.6	0.9579
1971	31.9	2.9	33.9	3.4	0.9903
1972	33.4	4.7	35.8	5.6	1.0096
1973	36.0	7.8	39.0	8.9	0.9999
1974	39.9	10.8	44.6	14.4	1.0225
1975	44.2	10.8	49.0	9.9	1.0171
1976	47.5	7.5	53.3	8.8	0.9860
1977	51.3	8.0	56.6	6.2	1.0634
1978	55.9	9.0	60.0	6.0	1.1407
1979	61.0	9.1	66.0	10.0	1.1714
1980	67.2	10.2	73.0	10.6	1.1692
1981	75.5	12.4	80.9	10.8	1.1989
1982	83.7	10.9	87.9	8.7	1.2337
1983	88.5	5.7	92.3	5.0	1.2324
1984	92.4	4.4	95.2	3.1	1.2951
1985	96.0	3.9	97.7	2.6	1.3655
1986	100.0	4.2	100.0	2.4	1.3895
1987	104.4	4.4	104.7	4.7	1.3260
1988	108.6	4.0	109.6	4.7	1.2307
1989	114.0	5.0	114.9	4.8	1.1840
1990	119.5	4.8	118.6	3.2	1.1668
1991	126.2	5.6	121.9	2.8	1.1457
1992	128.1	1.5	123.4	1.2	1.2087
1993	130.4	1.8	124.7	1.1	1.2901

Notes: (a) Seasonally adjusted.
Sources: CANSIM Series P490000, D20556, and B3400.

Table A.III-3 Silviculture Expenditures (Canada) (Millions of Current Dollars)

Year	Public funding						Industry	Other funding	Total
	Site preparation	Regene-ration	Tending	Marking	Silvicultural support	Total			
1977									118.3
1979									165.9
1981									272.9
1983									335.9
1985									480.6
1988									670.3
1989									684.0
1990	-	-	-	-	-	551.3	173.1	-	724.5
1991	-	-	-	-	-	571.0	231.6	0.3	802.9
1992	-	-	-	-	-	518.2	187.1	0.8	706.1
1993	-	-	-	-	-	483.5	182.3	0.6	666.4
1994	-	-	-	-	-	408.6	182.3	0.3	591.3
1995	-	-	-	-	-	429.7	380.0	-	809.7
1996	-	-	-	-	-	284.8	344.9	-	629.7

Notes: As of 1990, figures include provincial and private lands and federal land. Detailed figures are not available for expenditures funded by the industry. Other - other management expenditures" includes, as of 1991, public information, technology transfer, technology enhancement, integrated resource management, and other related agreement programs.
- implies zero value.
Source: National Forestry Database.

Table A.III-4 Contribution of Total Forest Industries to Canada's GDP and NDP (Millions $ (1986=100))

Year	GDP	GDP of total forest industires	Share of total forest industries	NDP	NDP of total forest industries	Share of total forest industries
	1)	2)	3)=2)/1)	4)	5)	6)=5)/4)
1970	291,506	10,814.6	3.71%	219,700	8,275.0	3.77%
1971	309,185	10,751.1	3.48%	232,887	8,204.8	3.52%
1972	329,713	11,486.0	3.48%	251,009	8,843.3	3.52%
1973	358,878	12,541.4	3.49%	276,169	10,002.9	3.62%
1974	386,692	13,281.7	3.43%	300,150	11,198.1	3.73%
1975	393,423	10,175.6	2.59%	310,493	7,566.4	2.44%
1976	421,676	12,242.6	2.90%	330,697	9,071.5	2.74%
1977	431,497	12,643.7	2.93%	334,984	9,337.0	2.79%
1978	439,224	13,626.9	3.10%	343,141	10,312.4	3.01%
1979	459,523	13,516.0	2.94%	362,492	10,209.8	2.82%
1980	469,115	13,626.0	2.90%	372,068	10,096.5	2.71%
1981	477,475	13,124.2	2.75%	371,883	9,704.3	2.61%
1982	453,685	11,026.8	2.43%	349,857	7,798.1	2.23%
1983	464,588	13,051.7	2.81%	359,550	9,242.6	2.57%
1984	486,200	14,046.0	2.89%	378,764	10,390.2	2.74%
1985	505,353	14,418.3	2.85%	393,479	10,725.6	2.73%
1986	511,796	14,873.2	2.91%	392,427	10,766.1	2.74%
1987	534,584	16,359.9	3.06%	409,230	11,712.3	2.86%
1988	563,338	16,529.0	2.93%	434,235	11,646.2	2.68%
1989	575,605	16,206.0	2.82%	438,725	11,136.8	2.54%
1990	567,477	15,246.5	2.69%	428,528	9,702.4	2.26%
1991	541,394	14,002.0	2.59%	404,580	8,105.1	2.00%
1992	545,311	14,378.3	2.64%	403,062	9,434.5	2.34%
1993	555,951	15,051.9	2.71%	408,832	10,037.3	2.46%
Average			2.96%			2.81%

Source: CANSIM Series D15661, D15665, I34103, I34116, and I34118.