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Assessing the Economic Impacts of Natural Disturbance Forest Management

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Assessing the Economic Impacts of Natural Disturbance Forest Management

by

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EXECUTIVE SUMMARY

The objective of this project was to construct the tools to assess the economic impact of a transition from sustained timber yield management to natural disturbance forest management. The impacts include not only timber values, but also non-timber values, community impacts, and other financial implications. Three main components of this research project have been developed. These are:

1. Defining Disturbance Based Management

In order to assess the economic implications of disturbance based management, some "definitions" of disturbance based management needed to be constructed. Thus, efforts were devoted to constructing forest level descriptions of disturbance based management. The natural disturbance paradigm is contrasted with a social science perspective to show the necessity of a hybrid approach for forestry management decisions

2. Impacts of Changing Management Regimes

   A. Financial Implications

Timber supply implications of moving to a disturbance based management approach were examined, using a "rate based" definition of natural disturbance management (NDM) and a simulation model of forest growth and harvest.

   B. Regional Economic Impacts (CGE Modeling)

Regional economic impacts of forestry developments in Alberta were estimated using two inter-industry approaches, input-output (I-O) models and computable general equilibrium (CGE) models.

   C. Implications of Changing Management Regimes: Non-Timber Impacts

An optimization model of natural disturbance based management was conducted to develop 100-year forecasts of probability distributions for habitat area of five vertebrate species under a stochastic wildfire regime.

3. Linking Economic Indicators (Timber and Non-Timber Values) with Ecological Conditions

Two approaches to linking economic indicators with ecological conditions were examined. The first approach was the construction of a natural resource account that included both timber and non-timber values for the region of the Alberta Pacific FMA. The second approach to linking economic and ecological conditions was the construction of an integrated economic-ecological model of non-market recreational hunting activity.

Many of the results of each of these components have been published in refereed journals while others are in working papers and/or under review at scientific journals. This report draws on those publications but includes discussions of the management implications of each of the components. The main findings of the research were:

1. Natural Disturbance-Based Management Harvest

- If NDM is defined by rate of disturbance, the allowable harvests may be significantly different than those derived from growth based techniques (the status quo).

- The degree of variability of natural disturbance rates makes it very difficult to identify a single harvest rate that emulates the rate of natural disturbance.
- The variability identified in natural disturbance suggests that it is unlikely that an “equilibrium” age class structure exists in the boreal mixed-wood forest.
- Disturbance estimates can be used to present trade-offs between critical habitat under “fire only” scenarios versus management and fire scenarios. In a case study, there were substantial differences in timber value realized, depending on the degree of deviation from a natural disturbance only (no harvesting) scenario.

2. Regional and Community Level Impacts

- More realistic assumptions (Computable General Equilibrium - CGE) dampen predicted shocks—traditional models tend to overstate the impacts of policy and management changes.
- Impacts on income distribution, in a regional text, can be evaluated using Social Accounting Matrix (SAM) methods
- Forest policies aimed at environmental conservation may be regressive.

3. Non-Timber Impacts

- Constructing regional resource accounts is possible and useful as an indicator of economic sustainability.
- In a case study of North Eastern Alberta, 60% of the total value was timber value, and 40% of values were from non-timber resources.
- Aboriginal subsistence value and carbon sequestration values are both individually greater than total values placed on recreation and on commercial values of fishing and hunting.
- Price risk has more impact on variability of resource accounting than does the risk of fire.

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1. DEFINING DISTURBANCE BASED MANAGEMENT[1]

In order to assess the economic implications of disturbance based management, some "conceptions" of disturbance based management needed to be constructed. Thus, efforts were devoted to constructing forest level descriptions of disturbance based management. The initial conceptions were based on the use of "mean fire rates" as a guide for allowable cut. This approach was then employed to assess the financial implications of employing this approach to allowable cut (relative to traditional growth and yield approaches to timber supply assessment). These results are discussed below. However, this analysis of the rate of disturbance led to additional investigation of the stochastic properties of disturbance.

The techniques used in this study consist of a simple statistical analysis to characterise the natural fire regime, and Monte Carlo simulations to examine the effects of the assumed fire regime on the precision of estimates of average burn rate and on forest age class distributions. The natural disturbance regime for the study area is characterised by large annual variations in the annual area burned. The distribution of annual area burned or burn rates is well-described by a lognormal distribution. The area burned in any one year can be modelled as an independent random draw from a lognormal distribution, constrained such that the area burned never exceeds the total area. This characterisation may also apply to other areas of the boreal mixedwood forest.

Estimates of average burn rates for the area developed through Monte Carlo simulation are highly imprecise even with very long sample periods (despite the fact that the mean of the natural logarithm of disturbance rate can be estimated precisely). A characterisation of the mean rate of natural disturbance is not precise enough to dictate harvest rate decisions under NDM management. The two-parameter characterization of the natural disturbance regime presented here could, however, be valuable for quantification of the risks associated with forest management and evaluation the effectiveness of fire suppression. Forest managers will make the harvest rate decision considering whatever factors are important to them, but defaulting to an unquantifiable natural disturbance rate is not an option.

By mimicking natural processes as closely as possible, NDM management is hypothesized to minimize the negative impacts of timber harvest on forest biota. This hypothesis allows the manager to focus on ecosystem process and structure, and how management techniques might emulate them, rather than on each species of concern. The applicability of this model to other study areas should also be examined. The lognormal characterisation of annual burn rate could provide a useful basis for evaluating fire risk, and in evaluating the effectiveness of fire suppression. This fire risk model could be incorporated into forest planning systems to better evaluate the timber supply and financial and ecological risks associated with forest fire.

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[1] Based on Armstrong, G. 1999. A stochastic characterisation of the natural disturbance regime of the boreal mixedwood forest with implications for sustainable forest management. *Canadian Journal of Forest Research.* 29(4): 424-433.

The natural disturbance based management perspective can be contrasted with other social science approaches to forestry policy making[2]. The social science perspective focuses on the value of externalities due to harvesting operations. These externalities can be positive or negative based on the perceived benefits to the individual and society. The impacts and values are assessed with the objective being maximization of net social benefits. The natural disturbance paradigm, however, considers the ecological effects of timber harvest. The main focus is that by maintaining "natural" disturbance based patterns on a regional scale, that sustainability will be achieved. Both of these perspectives are complex and contain many challenges and problems. The implementation of both processes would best reflect the environmental objectives in forest management decisions.

2. IMPACTS OF CHANGING MANAGEMENT REGIMES: FINANCIAL IMPLICATIONS OF NDM

A. Financial Implications[3]

A simple simulation model of forest growth and disturbance was constructed. It is used to compare the areas and volumes disturbed under different estimates of the natural disturbance rate with results from a sustained timber yield model (without disturbance). The areas and volumes disturbed under the natural disturbance scenarios can be usefully thought of as defining the upper limits to areas and volumes harvested under the single rate approach to natural disturbance management. The sustained yield scenario is intended to represent the status quo for harvest level determination in Alberta. Under the natural disturbance model, much less timber was available for harvest than under sustained timber yield management. It is shown that the schedules of harvest area and volume for the different scenarios are strikingly different. The model presented is an example of how a simple model can be a useful tool for evaluating the effects of a change in forest policy or practices.

The results provide some starting points for a discussion of disturbance-based management. In this study, two existing estimates of the natural disturbance rate for the area were used to define natural disturbance scenarios. The two natural disturbance scenarios provide extremely different projections of harvestable volume: in comparison to each other and to the sustained yield scenario. Thus we conclude that moving from sustained yield to natural disturbance models of forest management can have tremendous implications for the timber supply potential of an area, and that choosing "the natural disturbance rate" appropriate for a forest is both difficult and risky.

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[2] Based on Adamowicz, W. and T. Veeman. 1998. Forest policy and the environment: Changing paradigms. Canadian Public Policy. 14(2) S61-S61.

[3] Based on Armstrong G., S. Cumming, and W. Adamowicz. 1999. Timber Supply Implications of Natural Disturbance Management. *The Forestry Chronicle.* 75 (3):497-504

B. Impacts of Changing Management Regimes: Regional Economic Impacts (CGE Modelling)[4]

Input-Output (I-O) analysis, a class of inter-industry analysis, is by far the most commonly used technique for estimating economic impacts of changes in the forest sector. The information derived from I-O analysis often plays a key role in forest policy making thereby influencing the management of Canadian forests. A closer look at the underlying assumptions of I-O models raises serious concerns about the validity of the information derived from these models. For example, the assumptions that prices of inputs and outputs are fixed in the economy; production is based on a technology in which fixed amounts of inputs are required in order to produce a unit of output; there are no constraints on the supply of factor inputs; and final demand for the output of each industry is exogenous, may generate estimates that are biased. Forest policy decisions which are based on these estimates may be misguided.

Each of these assumptions may limit the applicability of I-O model in deriving socio-economic assessments of a change in policy. First, the assumption of fixed prices would not allow I-O models to capture the behavior of producers and consumers with respect to changes in the prices of inputs and outputs. According to this assumption, the supply of inputs or outputs has no influence on factor or product prices. Second, the fixed inputs assumption rules out the possibility of substitution between factors of production. According to this assumption, for example, an industry cannot expand its output in the short-run by combining increasing amounts of labor with its fixed capital stock. Third, if sectors are not directly linked by inter-industry flows of commodities, it is possible that they will still be interdependent since they compete for scarce primary factors (labor, capital, and land). With no constraints on the supply of primary factors, I-O models will not be able to account for these forms of interdependence. In other words, I-O models work well only for an economy in which producing sectors have excess capacity and primary factors are less than fully employed (Parmenter 1982). Finally, the exogeneity of final demand suggests that trading activity does not depend on relative prices. In consequence, I-O models are of limited usefulness for the analysis of international trade. Each of these assumptions may either overstate or understate the economy-wide impacts of any changes in the forest sector. In sum, I-O models are demand driven and do not incorporate supply constraints or substitution possibilities (Robinson and Roland-Holst 1988). These concerns have prompted economic modelers to propose an alternative inter-industry analytical tool, the computable general equilibrium (CGE) model, for policy analysis. This approach is thought to provide greater flexibility and generate less biased estimates when compared to I-O analysis.

Similar to an I-O model, a CGE model assumes that producing sectors of the economy are interdependent by supplying produced inputs to other sectors. However, this approach permits prices of inputs to vary with respect to changes in output prices and thus capture the

[4] Alavalapati, J., W. Adamowicz, and W. White. 1998. A Comparison of economic impact assessment methods: The case of forestry developments in Alberta. Canadian Journal of Forest Research. 28(5):711-719.

behavior of economic agents. It incorporates a variety of flexible production functions, which allow producers to substitute cheaper inputs for more expensive inputs. This model also can accommodate constraints on the availability of primary inputs and accounts for additional intersectoral linkages. For example, if factors of production are limited in supply, the expansion in some sectors will draw factors of production from other sectors thereby causing a contraction in those industries. Finally, a CGE model can explain final demand variables within the model rather than treating them as exogenous. Because of these assumptions, CGE models generate results that may be significantly different from those of an I-O model. Furthermore, depending upon the nature of the economy under investigation, each of these assumptions can be modified to a desired level. For example, the substitution between inputs can vary from no substitution to perfect substitution. Similarly, the supply of primary inputs also can vary from highly inelastic through elastic to highly elastic. Each modification will provide policy analyst a certain degree of flexibility to specify models that fit the economy under investigation. In sum, CGE models can capture nonlinear substitution possibilities and multi sectoral supply-demand interactions, and also incorporate macro variables and mechanisms for achieving balance among aggregates (Robinson and Roland-Holst 1988:353).

In spite of these attractive features, CGE models are less common, when compared to I-O models, in analysis of the Canadian forest sector.[5] In this study, it is demonstrated that CGE models provide greater flexibility when compared to I-O models in estimating the impacts of changes in the forest sector. Specifically, the impacts of a 22% increase in exports of pulp and paper products and a 1 % decrease in exports of wood products from Alberta are analyzed and the results are shown in Table 1 and Table 2.

The results from the I-O analysis suggest that a 22% increase in pulp and paper exports causes an increase in overall output, employment, and GDP. On the other hand, CGE models generate results that are different from the I-O models. Unlike I-O estimates, estimates derived from CGE models are not unidirectional. This is largely due to general equilibrium effects, which suggest that inputs are limited in supply and contraction/expansion in some sectors will cause expansion/contraction in some other sectors. Estimates derived from CGE models are smaller than those of I-O models. This is largely due to the changes in the prices of inputs and outputs in response to changes in their demand.

[5]This is not to suggest that CGE models have not applied to analyze the forestry sectors in Canada. For example, Percy (1986), Binkley et al. (1994), and Alavalapati et al.(1997) have applied the CGE approach to estimate the impacts of changes in the forest sector of British Columbia.

Table 1. Changes in output and primary factor prices in response to a 22% increase in exports of pulp and paper sector (Values are expressed in % changes)

Change in	IOWL	IOWOL	SCGE	MCGE	LCGE
Agricultural sector output (X1)	0.1572	0.3114	-0.2505	-0.3509	-0.3594
Logging sector output (X2)	4.972	5.0353	4.6314	4.7823	4.7769
Energy sector output (X3)	0.0632	0.1153	-0.066	-0.1013	-0.1047
Wood products sector output (X4)	0.1337	0.2082	-0.029	-0.085	-0.091
Pulp and paper sector output (X5)	18.3978	18.4128	18.0061	18.355	18.3535
Manufacturing sector output (X6)	0.2286	0.4766	-0.4924	-0.5936	-0.6067
Service sector output (X7)	0.1665	0.2405	0.0947	-0.01	-0.018
Wage rate	-	-	-	0.0175	0.0212
Overall capital rent	-	-	-	-0.01	-0.017
Rental rate of capital in X1	-	-	-1.1309	-	-
Rental rate of capital in X2	-	-	7.4308	-	-
Rental rate of capital in X3	-	-	-0.2262	-	-
Rental rate of capital in X4	-	-	-0.036	-	-
Rental rate of capital in X5	-	-	35.7032	-	-
Rental rate of capital in X6	-	-	-0.8871	-	-
Rental rate of capital in X7	-	-	0.1961	-	-
Overall output	0.2565	0.3581	0.051	-0.037	-0.045

Table 2. Changes in output and primary factor prices in response to a 1% decrease in exports of wood products sector (Values are expressed in % changes)

Change in	IOWL	IOWOL	SCGE	MCGE	LCGE
Agricultural sector output (X1)	-0.0034	-0.0066	0.0034	0.0061	0.0065
Logging sector output (X2)	-0.2105	-0.2119	-0.2022	-0.2069	-0.2066
Energy sector output (X3)	-0.0014	-0.0025	0.0009	0.0017	0.0018
Wood products sector output (X4)	-0.3957	-0.3973	-0.3914	-0.3915	-0.3912
Pulp and paper sector output (X5)	-0.0007	-0.0010	0.0002	0.0001	0.0002
Manufacturing sector output (X6)	-0.0047	-0.0099	0.0070	0.0107	0.0114
Service sector output (X7)	-0.0039	-0.0055	-0.0013	-0.0004	0.0000
Wage rate	-	-	-	-0.0006	-0.0011
Overall capital rent	-	-	-	0.0005	0.0009
Rental rate of capital in X1	-	-	0.0156	-	-
Rental rate of capital in X2	-	-	-0.3200	-	-
Rental rate of capital in X3	-	-	0.0030	-	-
Rental rate of capital in X4	-	-	-0.4875	-	-
Rental rate of capital in X5	-	-	0.0004	-	-
Rental rate of capital in X6	-	-	0.0127	-	-
Rental rate of capital in X7	-	-	-0.0028	-	-
Overall output	-0.0057	-0.0079	-0.0016	-0.0002	0.0003

The results of this study have a series of implications for forest policy analysis. For example, if the economy under investigation resembles that of the SCGE scenario, the choice of I-O models to estimate regional impacts of a policy change may result in biased estimates. This study shows that there is little scope for adjustment in I-O models to accommodate different economic situations. On the other hand, there is vast scope to modify CGE models to accommodate a variety of economic conditions. The scope of adjustment is limited only by the investigator's imagination and capabilities. However, the results also show that the CGE models can produce estimates that are "more biased" than those of I-O models. For example, in reality if the economy is similar to the SCGE scenario, the LCGE model will produce estimates that are more unrealistic than those of I-O models. Taken together the results suggest that CGE models have greater potential for policy analysis when compared to I-O models but they should be used with caution.

Distributive impacts of forest resource policies in Alberta

Historically, Alberta's forests were managed with an emphasis on optimizing timber harvests and revenues from timber products.[6] Environmental and recreational issues were not a priority in forest management. However, that is changing with an increasing concern for the environment and the growing demand for recreation from public forest lands. Activities taken to expand forestry operations may increase the production of forest products and thus create an increase in their exports. The increase in the cost of production and expansion of forest products exports may have economy-wide impacts with significant distributional consequences for various income groups. Information about economy-wide impacts and distributional consequences helps policy makers in re-designing regional economic development programs. In the discussion that follows, four types of changes relating to the forest sector in Alberta are discussed:

1) an $80 million increase in pulp and paper exports;
2) a $10 million decrease in lumber exports;
3) a 25% increase in the costs of timber production; and
4) a 25% increase in the costs of pulp and paper production in Alberta's forest sector are examined.

In this study, economy-wide economic impacts of these changes in the forest industry with an emphasis on distributional consequences are examined for poor, medium, and rich income households. Although the forest industry in Alberta is small, both in terms of value added and employment, relative to the rest of the economy, it may have significant linkages with the rest of the economy. Partial equilibrium analysis of changes in the forest sector cannot account for intersectoral linkages. Therefore, a social accounting matrix (SAM), (a multi-sectoral approach) is used to capture direct, indirect and cross effects of proposed changes. In this study, we use a SAM model to estimate changes in outputs and household incomes; analyze price formation and

[6] Based on Alavalapati, J., W. Adamowicz, and W. White. 1999. Distributive impacts of forest resource policies in Alberta. Forest Science 45(3): 342-348.

cost transmission mechanisms; and examine implications for household income in response to changes in the forest industry in Alberta.

Similar to input-output (I-O) models, SAM models account for intersectoral flows of intermediate inputs. However, SAM models go further to incorporate flows from producing sectors to factors of production and then on to government and households, and finally back to demand for goods (Adelman and Robinson 1986). A SAM details the direct linkages among its producing sectors and institutions and underlying indirect interactions. SAM provides a convenient framework to examine distributional impacts of changes in the economy. Furthermore, SAM based models are useful to examine price formation and cost transformation in economies with institutional rigidities (Roland-Holst and Sancho 1995).

SAM model is not without its limitations. First, the model assumes a Leontief production function. As such it does not allow substitution between factors of production. Second, factor demands do not depend on relative changes in factor prices. Therefore, the model is limited in capturing the behavior of economic agents in the economy. Third, the model assumes that the supply of factor inputs is unlimited in the economy. Therefore, any amount of expansion in one sector does not cause contraction in other sectors of the economy. Consequently, a SAM model may overestimate impacts of any changes. In spite of these limitations, SAM models are commonly used in estimating economy-wide impacts of changes and examining their welfare impacts because of the availability of data and their simplicity, relative to more complex Computable General Equilibrium (CGE) models.

The results of the quantity model suggest that higher income households get a larger share of the benefits than lower income households in response to an expansion in the pulp and paper sector. A contraction in the lumber sector also will hurt higher income households more than lower income households. Larger shares of medium and higher income households in total labor income and capital rents are identified as reasons for this asymmetric distribution. This may be the reason why high income groups either lobby for an expansion or oppose any contraction in forestry activities. The results of the price model suggest that additional costs associated with sustainable forest management and environmental regulations will hurt lower income households more than higher income households. The higher share of consumer expenditure in total income for lower income households when compared to that of high income households may be responsible for this result. Contrary to public agencies' expectations, the results of this study suggests that forest policies which are aimed to improve the environment may be regressive.

Environmentally extended regional economic impact analysis

The environmental extension of economic impact models is critical for more complete policy analysis. Environmentally integrated economic policy analysis, from a sustainable development perspective, requires a leap from conventional thinking and archaic modeling approaches. Sustainable development is a prevalent issue facing public and private decision-makers at a regional, national, and global scale. This issue is resulting in the introduction of environmental and natural resource policies aimed at mitigating environmental problems and promoting environmental stewardship.

General equilibrium methods are commonly used to inform policy-makers of the estimated economic impacts from a proposed change in policy or change in the economy. Recognition of the limitations of conventional general equilibrium economic impact analysis and increasing impact on the environment continues to fuel improvements in approaches to socio-economic policy analysis. Even so, few analytical models have been developed that extend economic impact analysis to include the environment.

In response, regional computable general equilibrium models that incorporate environmental considerations (carbon emissions and sequestration) were developed[7]. These models were used to evaluate the impacts of regionalizing economic data using hybrid and synthetic techniques, the efficacy of CGE models on a regional scale, and the environmental extension of CGE models on a regional scale. A total of seven models were developed in this study. Table 3 provides a summary of some of the basic features of the models. The first two models, the synthetic conventional SAM (SCSAM) and the hybrid conventional SAM (HCSAM), are used to determine whether the hybrid regionalization approach is more appropriate than the purely synthetic approach for the development of the remaining models.

Table 3: Summary of model features

	Role of Prices	Direction of Impacts	Major Adjustment Mechanism	Role of Environment
SCSAM	No Role	Unidirectional	-	-
HCSAM	No Role	Unidirectional	-	-
HESAM	No Role	Unidirectional	-	Used to Calculate Green NNP
SRHCCGE	Prices Endogenous	Multidirectional	Employment	-
LRHCCGE	Prices Endogenous	Multidirectional	Wages	-
SRHECGE	Prices Endogenous	Multidirectional	Employment	Indicator of Sustainability
LRHECGE	Prices Endogenous	Multidirectional	Wages	Indicator of Sustainability

The five remaining models, the hybrid environmentally extended SAM (HESAM), the short-run hybrid conventional CGE (SRHCCGE), the long-run hybrid conventional CGE (LRHCCGE), the short-run hybrid environmentally extended CGE (SRHECGE), and the long-run hybrid environmentally extended CGE (LRHECGE), are used to examine the differences between

[7] Based on Patriquin, M. (2000). Environmentally extended regional economic impact analysis. M. Sc. Thesis, Department of Rural Economy, University of Alberta, Edmonton, Alberta.

general equilibrium techniques and the integration of economy and environment. The general results are:

1. The comparison of a hybrid regionalization approach (mixed survey and synthetic) to developing a sub-provincial economic database or SAM (social accounting matrix) to a purely synthetic (computational) approach reveals that locally collected data is analytically important to the model.
2. A comparison of SAM (input-output based) models and CGE models reveals that estimates from the two approaches are different and that in general CGE impact estimates are more moderate due to the more realistic tradeoffs inherent in CGE models.
3. Development of regional CGE models is little more computationally demanding than the construction of regional I-O or SAM models demonstrating the efficacy of these techniques at the regional level and the potential for wider application of CGE models for economic impact assessments.
4. The regional CGE models were extended to include environmental variables that can be used as indicators of environmental sustainability. CGE models offer the most promise for the incorporation of non-market values and can be used to predict changes to environmental welfare resulting from policy changes or exogenous shocks to the economy.

The results demonstrate that impact estimates derived from SAM models based on a hybrid approach to data collection significantly vary from estimates derived from a model based on a synthetic technique. Table 4 demonstrates the differences between impact estimates derived from a synthetic versus a hybrid model. Since variation exists, the hybrid model is assumed to be the more accurate of the two approaches. The hybrid approach demonstrates a process of selective precision in regional data collection. The FMF hybrid model is used as the base for all other model extensions.

Table 4: Differences between hybrid and synthetic regionalization

	Forestry	Mining	CPNG	Wood	Visitor	ROE
Sectoral Shock (Dollars)	10000.00	10000.00	10000.00	10000.00	10000.00	10000.00
Economy-Wide Impact (HCSAM)	17742.96	16072.86	17218.28	14497.10	17888.11	18192.09
Economy-Wide Impact (SCSAM)	19348.07	22855.75	17868.61	21189.89	20552.29	11772.79
Actual Difference	1605.11	6782.89	650.33	6692.79	2664.18	-6419.31
% Difference	8.30	29.68	3.64	31.58	12.96	-54.53

The results from this study suggest that special consideration must be given to the development of regional economic databases. The results also indicate that variation exists between the impact estimates derived from I-O versus CGE models. In addition, the CGE approach offers more potential for environmental extension. This suggests that the CGE approach may be the tool of the future for more complete regional economic impact assessment.

C. IMPACTS OF CHANGING MANAGEMENT REGIMES: NON-TIMBER IMPACTS

A Monte Carlo simulation study of natural disturbance management was conducted to develop 100-year forecasts of probability distributions for habitat area of five vertebrate species under a stochastic wildfire regime[8]. These probability distributions are used to construct habitat constraints for use in an optimisation model allowing for quantification of the trade-offs between timber values and the "degree of naturalness" maintained in the forest. The model identifies the trade-offs between forest harvesting, wildlife habitat, and the degree of similarity between managed forest structure and the structural distribution generated by natural disturbance, and identifies shadow prices (in terms of net present value of timber production) for habitat area of each of the five species.

Non-market recreational hunting model

An integrated economic-ecological model of non-market recreational hunting was constructed in a STELLA framework. It was designed to illustrate how moose hunting preferences are affected by various attributes from a site. Among other things, the model can determine the percent of the total number of hunters that will go to each site given their preferences, as well as the combined aggregate welfare measures to see how total utility changes over time.

The model was divided into 3 habitats (each with a plant life, moose, predator, and hunter sector) as well as the option to not go hunting. The choices made by the hunters lead to their welfare, or, how well off they are made by the available options. These sectors together essentially "create" a sustainable dynamic simulation habitat for the moose.

The plant life sector is composed of several variables. There is an arbitrary initial quantity of vegetation affected by plant regeneration and moose consumption. The plant regeneration rates are affected by: the vegetation per hectare, total hectares of land, regeneration time, and initial vegetation. The total hectares of land are affected by the amount of land cleared by forestry. This is a non-linear function due to moose population increases from marginal forestry activity, and the reduction of moose population from excessive forestry.

The moose populations in this model are dynamic and are key in determining which site a hunter will choose. The higher the moose population is, the more likely it is that hunters will choose that particular site. An initial moose population is chosen, and that population is directly affected by: moose birth, moose starvation, hunted moose, moose density, and moose predation. Moose births are dependent on the population, as well as on moose natality (a graphed function), consumption per moose (from the plant life sector), and on the reintroduction of moose. Moose starvation is also dependent on population, moose mortality (a graphed function) and

[8] Based on Armstrong, G., W. Adamowicz, J. Beck, S. Cumming, and F. Schmiegelow. 2000. Integrated resource management in the context of the range of natural variability. SFM Working Paper 2000-9. 27pp.

consumption per moose. The moose density is dependent on the total number of hectares of land, as well as predation. Hunted moose is derived from the total % of hunters that go to that site (from the hunters sector). Similar to the dynamics of the moose population, the predator population is dependent on predator births and predator deaths, which are dependent on natality and mortality respectively.

The "hunters" sector is the sector that is most specific to this particular simulation model. There are 7 variables that feed into "hunting site attributes". The higher the value, the better the site is considered to be for hunting. The first variable that affects the attributes is "access within hunting areas". The more accessible the site is to a hunter, the more likely the hunters are to go there. The "quality of roads" variable was also included to include a hunter's preference for higher quality roads. The "distance to site" variable is negative for site choice—the further away the site is, the less likely that that site will be chosen. "Sensitivity to encounters" variable refers to how willing a hunter is to see other hunters hunting in a particular hunting ground (the higher the sensitivity, the more sensitive he is to congestion). The Sliders tool controls all the previous 4 variables to change attributes throughout the course of the simulation. Forestry operations (controlled by the dial tool) have a positive effect on moose populations and hunters to a certain point, and if over forested, the effect becomes negative.

The other variables that affect the hunting site attributes are all "self-sustaining" and endogenous. High levels of moose population (from the moose sector) increase the chances of a successful hunt, so the variable "moose population" is incorporated into the hunting site attributes. Also, the congestion levels (due to overcrowding of hunters) from the previous year negatively affect the number of hunters that will return to that site.

The "don't go hunting" sector creates the option to not go hunting at all if the hunting choices are poor. There is a constant value for "not hunting attributes" that feeds into the equation that calculates the percentage of hunters that will not go given those 3 hunting options. The "welfare measures" sector calculates the welfare of the hunters to assess the satisfaction with the hunting experience. These measures determine the monetary impact of changes in non-monetary variables. A logarithmic equation calculates the welfare on a yearly basis. The change in welfare helps to determine overall hunting satisfaction, predict congestion areas, and examine different policies to graph their effects. This model could also be used to calculate expenditures on hunting (which affect economies in the region of the habitat).

3. LINKING ECONOMIC INDICATORS (TIMBER AND NON-TIMBER VALUES) WITH ECOLOGICAL CONDITIONS

Two approaches to linking economic indicators with ecological conditions were examined. The first approach was the construction of a natural resource account that included both timber and non-timber values for the region of the Alberta Pacific FMA. This results in the construction of an indicators of economic sustainability that considers both market and non-market values. The results of this exercise are summarized in Table 5.

Table 5. Summary of the 1996 Forest Resource Account for Study Region (1996$, millions)

		Low	High	Average	Range of Uncertainty	% of Average Total Net Income	
Commercial Forestry							
Pulp Production		86.6	132.6	109.6	46.0	47.2	
Lumber Production		60.0	60.0	60.0	NA	25.8	
Subtotal				169.6			72.9
Change in Timber Capital		44.4	60.2	52.3	15.8	22.5	
Change in Human-made Capital	Pulp	-61.4	-84.2	-72.8	22.8	-31.3	
	Lumber	-5.3	-5.3	-5.3	NA	-2.3	
Subtotal				-25.8			-11.1
Total				143.8			61.9
Other Commercial Uses							
Fishing		0.29	0.29	0.29	NA	0.1	
Trapping		0.27	0.51	0.39	0.24	0.2	
Subtotal				0.68			0.3
Recreational Use							
Hunting		0.28	0.97	0.62	0.7	0.3	
Fishing		0.52	2.65	1.58	2.1	0.7	
Camping		0.21	0.21	0.21	NA	0.1	
Subtotal				2.41			1.0
Subsistence Uses							
Aboriginal Land Use		8.3	26.8	17.6	18.5	7.6	7.6
Passive Use							
Biodiversity Maintenance		14.8	102.1	58.4	87.3	25.1	25.1
Environmental Control Service							
Carbon Sequestration		0.2	18.9	9.5	18.7	4.1	4.1
Total Net Income		149.2	315.7	232.4	166.5	100.0	100.0

Using average component values, the largest component of total net income in the forest resource account is pulp production and the smallest is camping. Other large absolute values include human-made capital depreciation, biodiversity maintenance and value of change in the timber stock.

The incorporation of risk and uncertainty are also important when calculating values for resource accounts. The expected value of risk helps to apply a stochastic version of a sustainability rule that requires that the value of the net income to be non-declining. Results show that net income is subject to large and stochastic declines the influence of fire risk. When the price risk is also incorporated, the expected value of these forms of risk is estimated to be $11 million annually.

The second approach to linking economic and ecological conditions was the construction of an integrated economic-ecological model of non-market recreational hunting activity. This prototype model outlined how human behaviour (recreation site choice), ecological conditions (wildlife populations, vegetation), and access interact to generate time varying non-timber benefits. This model also served to identify several uncertainties in the modelling of these systems, particularly the interaction between economic agents, and the impact of dynamics (demographic changes and habit persistence) on non-market benefits.

***Regional Forest Resource Accounting: A Northern Alberta Case Study*[9]**

Dissatisfaction amongst economists and researchers from other fields with the use of GDP or GNP as an indicator of a country's progress and aggregate welfare led to calls for adjustments to this measure of national income. The field of resource accounting was initiated by those who felt that conventional national accounting inadequately reflected the effects of environmental degradation and of natural capital depletion on national welfare. Much like conventional income accounts, resource accounts document economic activity; however, resource accounts include the flow of income from non-market activities and the value of natural capital depreciation. Therefore, resource accounts can give a broader picture of aggregate welfare. Resource accounts have also been used for policy assessment and planning by a number of countries.

In combination with other information, natural resource accounting can be used to assess the socioeconomic sustainability of forestry practices. This report outlines the development of a regional level resource accounting system for a forest products company operating in northeastern Alberta. The purpose of this exercise is to provide a clearer picture of the direct and indirect benefits provided by the forest. The case study provides the basis for future estimates that when tracked over time can provide information regarding the sustainability of income flows from the region. Many of the complexities of resource accounting at this finer resolution parallel those of resource accounting at the national level, however, the case study also illustrates constraints and challenges unique to the regional and forestry context.

The resource accounting framework developed for the case study region is used to estimate the income generated by forest services in 1996. The services valued include commercial activities such as forestry, trapping, and fishing and non-commercial or non-market activities. The non-market services valued include recreational activities (fishing, hunting, and camping), subsistence resource use, and environmental control services (carbon sequestration and biodiversity maintenance). The appropriate methods for estimating component values are not always straightforward and in some cases different methods are compared. Also, for some components a range of possible values is given based on the information available related to activity levels and the marginal net value associated with the activity.

It is estimated that the forest services included the resource account generated between $149 and $316 million in net income in the region in 1996. Commercial forestry was the largest

[9] Haener, M. and Adamowicz. W. 1999. Regional Forest Resource Accounting: A Northern Alberta Case Study. Canadian Journal of Forest Research. 30 (2): 264-273.

component of the account representing approximately 62% of the total average net income. Aboriginal resource use and biodiversity were the largest of the non-market values estimated and also had the largest degree of uncertainty associated with them.

The study demonstrates that regional forest resource accounting is feasible and can provide valuable information to forest managers. However, the accounting exercise also reveals a number of complications and difficulties that need to be overcome. The report provides numerous recommendations and suggestions for future research related to the estimation of forest service values and the construction of forest resource accounts.

Incorporation of risk in regional forest resource accounts[10]

Uncertainty and risk are associated with future income flows from forest resources. The uncertainties associated with timber harvesting income stem from both uncertainty in future environmental conditions and uncertainty in market conditions. Changes in environmental conditions (such as weather and fire) can alter the growth and characteristics of timber stock, and thereby influence commercial forestry, recreational activity, biodiversity and other forest services. Market conditions can also influence the future forestry income flows, by way of price fluctuations and changes in consumer preferences, development of substitutes and technological advancements. Because of the influence of uncertainty on the regional net income from forest services, it is important to include the expected appreciation or depreciation of capital stocks in the income measure.

The methods that were used in this study included a series of simulations to demonstrate how fire and price risks influence regional resource revenue flows and timber stocks. The future paths of resource revenue and changes in merchantable timber stock were simulated using two approaches: Repetto's depreciation approach and Brekke's wealth–based approach. The simulations predict revenue flows and stock changes for the next 20 years, and for each of the 20 years, 500 draws are made from the probability distribution characterizing fire and/or price risk.

Firstly, the fire simulations were conducted. Armstrong's (1999) findings were used to assume that a relatively simple non-spatial stochastic characterization of fire risk predicts as well as other models. The distribution of fire risk was characterized as a lognormal with a mean annual burn rate of 0.006296% of forest area and S.D. 2.853. Deciduous and coniferous harvest levels were both considered, as well as differences between quota holders. Annual growth and land conversions were assumed to remain constant at the 1996 levels.

When the depreciation approach was used, the path of net income displayed was highly uncertain. Since the depreciation approach adjusts current income flows by the value of the change in stock for that year, the variability is reflected directly in the net income measure. When the wealth-based approach is used, the path of the mean or expected net income is much

[10] Based on Haener, M.K., and Adamowicz, W.A. 2000. Incorporation of risk in regional forest resource accounts. Ecological Economics. 33: 439-455.

smoother, and the path of the net income is higher. The confidence intervals increase over time, but do not fluctuate greatly.

Next, a price risk simulation was conducted. The simulated price paths were based on historical time series data. As with the fire simulations, 500 draws for each of the 20 years are made from the error term distributions. The results showed that in using the two approaches, the shapes of the curves were similar; however, the wealth approach generated a time path, which is less variable. The depreciation approach resulted in a distribution with a slightly larger range and median.

By simulating both fire and market risks, a more realistic approach with more applicable results to timber net income is formulated. The combined simulation can be seen in Table 6.

Table 6. Price and fire risk simulation summary statistics: net income, years 1-20

Annual net income statistic	Average of annual	Lowest of annual	Highest of annual
Depreciation approach			
Mean	137 330 540	60 405 755	241 060 246
Lower 95% confidence interval	-642 290 552	-1 357 505 422	-82 846 996
Upper 95% confidence interval	497 696 587	315 087 376	591 251 783
Wealth approach			
Mean	208 402 188	115 950 744	268 417 402
Lower 95% confidence interval	30 473 649	-23 932 034	177 537 244
Upper 95% confidence interval	376 991 472	185 849 964	448 431 123

The influence of fire risk appears to dominate since the resulting figure closely resembles the corresponding chart for fire risk. The time path of net income when the wealth approach was used was less stochastic than the path generated when the depreciation approach was used. This is because when the depreciation approach is used, the entire appreciation in resource stock for the year is added from income flows or the year. Therefore, if the volume or the price of the stock fluctuates over time, then the net income will as well. However, in renewable resources, this adjustment overestimates changes in productive capacity of the resource. For example, it does not account for the ability of the resource to regenerate in future periods, essentially treating them as permanent deletions.

However, the wealth approach uses information related to future revenue flows to value current stock changes. It allows the change in future resource flows due to fires and cutting in the current period to be captured in the net income estimate for the current period. Therefore, when a renewable resource is subject to risk, the wealth approach is a more appropriate measure.

CONCLUSIONS

In assessing the transition towards a natural disturbance management regime in the boreal forest, it is important to examine economic impacts and changes. In order to accurately assess the economic implications of a natural disturbance regime, there needed to be a consistent description of "natural disturbance" management.

Several sets of tools for assessing the impacts of changing management regimes were developed. Firstly, the financial implications were studied. Next, regional economic impacts tools were developed, including CGE models, SAM models and Input-Output models. Also, the non-timber aspects were examined to assess how non-market values could be incorporated into economic assessments.

The final aspect considered in this project was linking the economic indicators to ecological conditions. This was achieved by constructing an integrated ecological/economic model to portray recreational hunting activity and the effects on non-market attributes.

The main conclusions of the elements of this research program were:

- A comparison between NDM and growth-based techniques leads to a significant difference in allowable harvest levels as well as timber values
- A hybrid of both NDM and a social science perspective need to be incorporated to get a more accurate valuation of the environment to better create forestry policy.
- Estimates derived from input-output (I-O) models differ from those of computable general equilibrium (CGE) models. Employment and GDP estimates derived from CGE models are much smaller than those estimates derived in I-O models.
- In order to test the incidence of changes in regional level forest industry activity, a Social Accounting Matrix (SAM) approach was developed. The results of the quantity model suggest:
    - Higher income households get a larger share of the benefits than lower income households in response to an expansion in the pulp and paper industry.
    - A contraction in the lumber sector will hurt higher income households more than lower income households.
    - The results of the price model suggest that additional costs associated with sustainable forest management and environmental regulations will hurt lower income households more than higher income households.
- An economic-ecological model is a good illustration of the variables and players involved in the complexity of ecosystem dynamics.
- Regional resource accounts provide an effective and useful method of assessing economic sustainability.

- When a renewable resource is subject to risk, the wealth-based approach is a more appropriate measure of sustainability than the depreciation approach.

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